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Transport of Pesticides From Irrigated Fields In Surface Runoff and Tile Drain Waters

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Abstract

Spencer, W. F., M. M. Cliath, J. W. Blair, and R. A. LeMert. Transport of pesticides from irrigated fields in surface runoff and tile drain waters. 1985. U.S. Department of Agriculture Conservation Research Report No. 31, 76 p.

Pesticide concentrations were determined in samples of surface irrigation runoff water following the application of pesticides to large fields of cotton, sugarbeets, alfalfa, lettuce, onions, and cantaloupes in Imperial Valley, Calif. The concentrations and total amounts of pesticides removed from treated fields in runoff water were dependent upon the characteristics of the pesticides, their methods and rates of applications, the time elapsed between application and the first irrigation, the number of irrigations since the pesticide application, irrigation efficiency, and other soil management practices. Highest runoff rates occurred when herbicides were applied in irrigation water.

Herbicides applied directly to the soil were found in runoff in higher amounts than aerially applied insecticides except when the insecticide applications coincided with the irrigation event. Concentrations were highest in the first irrigation following pesticide application. Time elapsed between pesticide application and the irrigation event was inversely related to log concentration, indicating an approximate first-order rate of decrease in runoff concentration with time.

The concentrations and amounts of pesticides in the 0- to 1-cm depth of soil proved to be good indicators of the concentrations and amounts of pesticides to be expected in runoff water under furrow irrigation systems used in the Imperial valley. The amounts of sediment in runoff water, the runoff water volume, and the accumulative water applied were not highly correlated with amounts of pesticides in runoff. The percentages of the applied pesticides lost in runoff water were generally very low with all seasonal totals for insecticide runoff below 1 percent of the amounts applied. Seasonal losses of the soil-applied herbicides were usually 1 to 2 percent of the amounts applied. Runoff losses of water-applied EPTC varied from 2.6 to 13 percent of the application.

Except for the pyrethroids, most of the pesticides were transported in the water phase. None of the pesticides were identified in tile drain effluents at concentrations above minimum detectable levels of 1 to 2 parts per trillion, indicating that most of the presently used pesticides are not sufficiently persistent, or they are not sufficiently mobile, to reach ground water in the relatively heavy soils in Imperial Valley.

KEYWORDS: pesticides, insecticides, herbicides, pesticide runoff, pesticide transport, irrigation runoff water, herbicide runoff, insecticide runoff, irrigation.

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Acknowledgments

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This paper contains the results of research only. Mention of pesticides does not constitute a recommendation for use, nor does it imply that the pesticides are registered under the Federal Insecticide, Fungicide, and Rodenticide Act as amended. The use of trade names in this publication does not constitute a guarantee, warranty, or endorsement of the products by the U.S. Department of Agriculture.

Transport of Pesticides From Irrigated Fields in Surface Runoff And Tile Drain Waters

By W. F. Spencer, M. M. Cliath, J. W. Blair, and R. A. LeMert[1]

Introduction

The use of pesticides has resulted in enormous benefits to humanity chiefly in the areas of public health and agricultural production. In today's agriculture, the use of chemicals is clearly necessary to maintain high yields and high quality of agricultural products and to provide economic benefits to farmers and consumers. In spite of all the benefits from the use of pesticides, there is a conflict of interest because of the possibility of harmful impacts on environmental quality. In today's concern for clean water, there are increasing demands for preventing pesticides and other pollutants from entering water supplies. Agriculture has received considerable blame for the presence of pesticides in surface and ground waters.

There are many pathways by which pesticides leave sites of application and distribute throughout the environment. One such pathway is the movement of these chemicals away from treated fields in runoff water and on sediment carried along in the water. Many investigators have reported pesticide losses in water from runoff of rainfall in humid areas, but practically no data are available on amounts of pesticides in runoff or drainage water from individual irrigated fields in the Western United States. The subject of pesticides in agricultural runoff from rainfall was reviewed by Caro *(1976)* and Wauchope *(1978)*.[2] Knisel *(1980)* recently assembled a model called CREAMS (chemicals, runoff, and erosion from agriculture management systems) for evaluating amounts of pesticides in surface runoff from rain-fed agriculture. Their reports led to the general conclusion that, except when heavy rainfall occurs shortly after treatment, pesticide concentrations are very low and the total amounts of pesticides removed from the land in runoff during the crop year is usually much less than 5 percent of the application.

Studies on pesticides in drainage waters from irrigated agriculture have been limited to monitoring the concentrations of pesticides in large drains (Bailey and Hannum, *1967*; Glandon and Beck *1969*; Irwin *1971*; California State Water Resources Control Board *1971*; Eccles *1979*; Beck *1980)*. Eccles *(1979)* monitored specified drains at monthly or bimonthly intervals in the southeast desert area of California. He reported that concentrations of pesticides detected in the drains fluctuated widely and that frequency of detection and concentration of pesticide residue were higher in drains receiving surface runoff. Surface drain effluents from the Central Valley have also been observed to contain higher concentrations of pesticides than subsurface drain effluents (Johnson et al. *1967*; Beck *1980)*.

The development of soil, water, crop, and pesticide management practices to minimize detrimental effects of pesticides on the environment requires data on factors influencing pesticide concentrations or total amounts in drain waters. The current work is aimed at determining concentrations and amounts of pesticides carried off treated fields in surface or subsurface drainage effluents and pinpointing the potentially controlling factors affecting these amounts. Such data are useful in quantitatively assessing the pollution potential of irrigated agriculture and for developing management practices to minimize the amounts of pesticides in runoff and drainage waters.

The purpose of this publication is to provide data on the soil, the nature of pesticide, crop, soil, irrigation, drainage, and pesticide management practices related to the transport and fate of pesticides applied to irrigated crops. The publication provides details of sampling, analysis, and supplemental information required to evaluate the data and contains recommendations for developing management practices to decrease the transport of pesticides from irrigated fields.

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 62.

Description of Study Area

The experimental sites were large fields in the Imperial Irrigation District, which lies within the Imperial Valley in southern California. The irrigated acreage of the Imperial Irrigation District is about 500,000 acres, most of which is below mean sea level. The desert climate is characterized by hot, dry summers and mild winters with temperature extremes ranging from -5° to 52°C and a mean annual temperature of 23°. Daily maximum temperatures exceed or equal 38° more than 100 days per year. Rainfall averages about 6 cm per year. This climate is ideal for irrigated agriculture and allows a 365-day growing season. Of the approximately 200,000 hectares (ha), 65,000 ha are in alfalfa, 3,000 are in orchards and asparagus fields, and 30,000 are double cropped with vegetables or melons followed by small grain. Most of the remaining area is used for field crops, including cotton, sugarbeets, wheat, barley, and sorghum.

The Colorado River is the source of irrigation water in the Imperial Valley with water being conveyed from the Colorado River to the Imperial Valley in the 130-km-long All-American Canal. It flows to individual fields by way of gravity canals and field head ditches. Irrigation is principally supplied by gravity surface methods through furrow or border irrigation systems. Most fields are designed to prevent standing irrigation water, which results in surface runoff during irrigation. At present, the surface runoff is discharged to the agricultural drains.

Salinity control is one of the major soil management concerns in the Imperial Valley area. Salinity is controlled by leaching the salts down through the soil below the root zone by means of irrigation water. Since effective leaching depends on good drainage, water tables are controlled effectively by tile drains to keep the water table below 1.4 m to inhibit capillary rise of salts to the soil surface. A trunk system of open drains serves to carry tile discharge and irrigation waste water to the Salton Sea, either directly or via the Alamo and New Rivers. Most of the soils are fine or moderately fine textured derived from lake bed sediment. They are mostly slowly permeable.

Irrigation water management is extremely important in the area. Good management can supply plant needs and flush salts from the root zone without excessive waste of the limited water supply. For surface irrigation of soils with slow water intake rates, fields are leveled to a very gentle slope so that the water flows slowly over the surface and can infiltrate before it reaches the far end of the field.

Pesticide usage reports on file with the Imperial County Agriculture Commissioners Office indicate that pesticides may be used any month of the year. Pesticides are applied from the air, by ground rigs, or in irrigation water. Insecticides are applied primarily from aircraft, whereas herbicide applications usually consist of spraying, spreading, or injecting into the soil. Some herbicides, such as EPTC, are applied in irrigation water.

Methods and Materials

Field Procedures

Pesticides were determined in irrigation return flows from surface irrigation runoff water and tile drainage water under various irrigation practices used by farmers on large fields varying in size from 28 to 60 ha. The farmers determined the crops to be grown on the fields and the pesticides to be applied. Each field was instrumented with a propeller water meter for measuring volumes of incoming irrigation water, a Parshall flume for measuring outgoing runoff water, and slotted tubes on tile lines for measuring tile drainage water volumes. Many of the pesticide runoff samples were obtained from field sites (fields 3-7) instrumented to measure water volumes by personnel of the USDA-ARS Imperial Valley Conservation Research Center, Brawley, Calif., and the Imperial Irrigation District to develop methods for improving irrigation efficiency.

The experimental sites were characterized by soil type descriptions from soil maps of the individual fields. The soil types at each field site are shown in table 1 along with the percentage of the total acreage in each soil type. Seven of the sites used for the majority of the sampling were further characterized by obtaining soil samples for determination of particle size distribution, soil organic matter content, and other properties associated with runoff of pesticides. For this purpose, the fields were core sampled to a depth of 30 cm by quadrants, with a total of 15 cores per quadrant composited into four samples per field. Soil properties determined on these samples from fields 1 to 7 are shown in table 2.

Pesticides were determined in irrigation runoff water from fields planted to cotton, sugarbeets, lettuce, alfalfa, cantaloupes, and onions irrigated with furrow or border surface irrigation systems during 1978 to 1982. The following information was gathered concerning the pesticides application: date, rate and time of application, method of application, pesticide formulation, and percent canopy coverage by the growing crop at the time of application. All insecticides in the study were aerially applied except where noted otherwise. Herbicides, except EPTC and cycloate, were applied with a ground rig directly to the soil. EPTC was applied in surface irrigation water at approximately 2 p/m EPTC in all cases. Cycloate, a preemergence herbicide, was applied to sugarbeets in 1979 by sprinkler irrigation during the so-called germination irrigation. The sprinkler irrigation resulted in no runoff.

Before some irrigations, soil samples to the 1-cm depth were collected from the irrigation furrow, or the area to be wetted, to relate soil concentrations to pesticide runoff. Except in loose soil, samples were obtained with a 3-cm-diameter stainless steel tube with a metal plug installed in the tube to prevent samples from being taken to a depth greater than 1 cm. In loose soil, samples were taken to approximately the 1-cm depth with a small metal cup. For calculating pesticide concentrations in loose soils, the volume of the sampling cup was equivalent to three 1-cm cores from the soil tube. The number of samples per field varied generally from 4 to 11 with each sample consisting of approximately 20 to 150 cores. Soil samples were

Table 1. — *Soil types present on field sites, percentage of the total area, and estimated range of water permeabilities for each soil type*[1]

Field		Soil type		
No.	Area	Name	Percent of total	Permeability
	Ha			*Cm/hr*
1	28	Imperial silty clay	100	0.15-0.50
2	28	Holtville silty clay	80	0.15-0.50
		Imperial-Glenbar silty clay loam	20	0.15-1.5
3	28	Holtville silty clay	50	0.15-0.50
		Vint loamy very fine sand	25	5-15
		Meloland-Holtville loam	25	1.5-5
4	54	Imperial-Glenbar silty clay loam	75	0.15-1.5
		Imperial silty clay	25	0.15-0.5
5	60	Imperial-Glenbar silty clay loam	70	0.15-1.5
		Imperial silty clay	30	0.15-0.5
6	53	Imperial-Glenbar silty clay loam	95	0.15-1.5
		Imperial silty clay	5	0.15-0.5
7	58	Imperial silty clay	75	0.15-0.5
		Imperial-Glenbar silty clay loam	25	0.15-1.5
8	28	Imperial silty clay	90	0.15-0.5
		Imperial-Glenbar silty clay loam	10	0.15-1.5
9	56	Vint loamy very fine sand	40	5-15
		Holtville silty clay	35	0.15-0.5
		Vint-Indio very fine sandy loam	20	1.5-15
		Imperial-Glenbar silty clay loam	5	0.15-1.5
10[2]		Holtville silty clay	100	0.15-0.5

[1]From Soil Survey of Imperial County, Calif., Imperial Valley area (USDA, SCS *1981*)
[2]Small plots at Imperial Valley Conservation Research Center, Brawley, Calif.

Table 2. — *Average*[1] *physical and chemical properties of surface soils at field sites 1-7*

Field	Particle size distribution			Organic carbon	Paste saturation	Paste pH	EC	Average texture
	Sand	Silt	Clay					
	Percent						$DS \cdot m^{-1}$	
1	20	34	46	0.54	52	7.7	2.3	Clay
2	13	38	49	.56	58	8.0	2.2	Silty clay
3	25	47	28	.38	45	7.7	2.5	Clay loam
4	5	46	49	.74	59	7.6	3.4	Silty clay
5	7	42	51	.52	58	7.9	6.3	Do.
6	11	51	38	.71	58	7.8	4.9	Silty clay loam
7	5	47	48	.96	56	7.7	2.9	Silty clay

[1]Each value is an average of 4 composite samples of 15 cores each to a depth of 30 cm.

placed in paper bags inside plastic bags and stored frozen until they could be prepared for analysis. Sampling variability was evaluated by obtaining 20 to 120 cores per sample. The coefficients of variation decreased from 40 to 15 percent as the number of cores increased from 20 to 120 cores per sample. With this variability, eight samples per site with 80 cores per sample or six samples with 100 cores per sample resulted in an allowable error of only ±15 percent.

Intensive grab sampling of runoff water following pesticide application established the relationship between pesticide concentration and the water runoff hydrograph, which was used to indicate the minimum frequency of sampling needed to adequately evaluate the total outflow of pesticides. This relationship indicated that irrigations immediately following a pesticide application should be sampled more intensively than subsequent irrigations. During the first irrigation after a pesticide application, runoff water was sampled approximately every half hour; runoff during the second irrigation was sampled at half-hour intervals for the first 2 or 3 hr then at 2- to 4-hr intervals for the remainder of the runoff period; subsequent irrigations were sampled four to six times per runoff event. In most cases, sufficient irrigations were sampled to allow the calculation of total pesticide runoff during the growth of each crop.

Water samples were obtained from the throat of the runoff flume, the head irrigation ditch, or the tile outlet by hand sampling with a beaker and transferring the water into a 1-liter (L) Pyrex glass bottle. The samples were immediately placed into an ice water bath in an ice chest. They remained in the ice chest during transport and were then stored in a coldroom at 4°C prior to processing in the laboratory.

In early 1980, we found that some of the organophosphate insecticides were unstable in high pH waters resulting from anhydrous ammonia applications. Consequently, after April 1980, we added 2 g/L KH_2PO_4 to all runoff water samples immediately after they were obtained from the runoff flume to buffer them to a pH of approximately 6.0 to prevent pesticide degradation. These precautions were in addition to the usual procedures for transporting samples in ice and storing them at 4°C prior to extraction.

The pesticide content of 1-L tile drainage water samples was below detectable levels for all pesticides. This led us to develop a solid-phase sampling system utilizing a pressurized sample container and XAD-2 macroreticular resin columns to extract pesticides from large-volume water samples. This method allowed the onsite concentration of pesticides in 10- to 30-L water samples, which greatly extended the range of detection of trace pesticides in tile drain waters. The high pressure collection system consisted of a 10-L stainless steel dispensing pressure vessel, compressed nitrogen to dispense the water samples through the filtering system, and XAD-2 resin for trapping the pesticides. Even with these large water samples, pesticide concentrations in tile drain waters were below minimum detectable levels. Consequently, this report deals mainly with pesticides in irrigation return flows from surface irrigation runoff waters.

Laboratory Procedures

Water Analyses. In the laboratory, each water sample was analyzed for recently applied pesticides of interest and the sediment load was determined. Water samples were analyzed for a total of 20 pesticides (14 insecticides and 6 herbicides). The 20 pesticides with their common names and chemical designations are shown in table 3. Whole water samples (water and sediment) were extracted four times by liquid-liquid extraction with 50 ml of organic solvent to 500 ml water by shaking in a separatory funnel. The extracts were dried with sodium sulphate and concentrated to 5 ml or less using a Nujol-hexane keeper in a Kuderna-Danish apparatus. Pesticide concentrations in the extracts were determined by gas-liquid chromatography (GLC) using appropriate detectors for the pesticide of interest. Methomyl residues were converted to the oxime derivative in dilute alkaline solution prior to GLC analyses. Other pesticides were not altered prior to analyses. Table 4 briefly summarizes the extracting solvent

and GLC detector used for each pesticide along with minimum detectable levels for each based on a 500-ml water sample, extract concentration to a final volume of 5 ml, and a 5-μl injection. The actual minimum detectable levels depended upon the final extract volume used for each analysis and were calculated from the information for 5 ml.

Sediment concentrations in runoff water samples were determined by filtering 50- or 100-ml aliquots of the water through glass fiber filters (Whatman GF/C, 0.26 mm thick) in small Gooch crucibles under suction. The sediment was dried at 105°C for 2 hr before weighing.

Soil Analyses. Soil samples obtained from the 0- to 1-cm depth from treated fields were screened through a 4-mm screen and mixed thoroughly. Fifty-gram soil samples were soxhlet extracted with 250 ml of a 1:1 mixture of acetone and hexane for 4 hr. The extracts were concentrated to the appropriate volume and analyzed by GLC with detectors as indicated in table 4. The efficiency of extraction from water and soil of each pesticide determined by fortifying samples with known amounts of each pesticide was greater than 90 percent, except for permethrin (87 percent) and endosulfan (87 percent).

Storage Stability. The stability of several organophosphate insecticides and herbicides in irrigation runoff water during storage at 4°C was determined by measuring their degradation rates. Ethyl parathion, methyl parathion, diazinon, methidathion, EPTC, prometryn, and dinitramine were added at three concentrations to runoff water adjusted to a pH of 9.0, 8.0, and 6.0. The pH 8.0 water was unaltered irrigation runoff water, the pH 9.0 water contained ammonium hydroxide, and the pH 6.0 water contained approximately 2 g/L KH_2PO_4. The pesticide-treated water was analyzed initially and then subsequently at various intervals from 2 days to 8 weeks after storage at 4°C.

All the compounds were found to be stable in the runoff water with the exception of ethyl parathion, methyl parathion, and diazinon. These three compounds were stable in water buffered at pH 6.0, but at pH's of 8.0 and 9.0 they degraded with a half-life of approximately 6 days following a lag of 1 week before degradation started. On the basis of these findings, we subsequently added 2 g/L KH_2PO_4 to runoff water samples to buffer them to a pH of approximately 6.0 to prevent degradation. The runoff values for ethyl parathion, methyl parathion, and diazinon obtained prior to initiating the practice of adding KH_2PO_4

Table 3. — *List of herbicides and insecticides by common name, trade name, and chemical name*

Common name	Trade name	Chemical name
		Herbicides
Cycloate	Ro-Neet	S-ethylcyclohexylethylthiocarbamate.
DCPA	Dacthal	dimethyl tetrachloroterephthalate.
Dinitramine	Cobex	N^4,N^4-diethyl-α,α,α-trifluoro-3,5-dinitrotoluene,2,4-diamine.
EPTC	Eptam	S-ethyl dipropylthiocarbamate.
Prometryn	Caparol	2,4-bis(isopropylamino)-6-(methylthio)-*s*-triazine.
Trifluralin	Treflan	α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine.
		Insecticides
Azinphosmethyl	Guthion	*O*,*O*-dimethyl *S*-[(4-oxo-1,2,3-benzotriazin-3(4*H*)-y1)methyl]phosphorodithioate.
Chlorpyrifos	Lorsban, Dursban	*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl)-phosphorothioate.
Diazinon	Diazinon	*O*,*O*-diethyl *O*-(2-isopropyl-4-methyl-6-pyrimidinyl)phosphorothioate.
Endosulfan	Thiodan	6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzo (e)-dioxathiepin-3-oxide.
Ethylan	Perthane	1,1-dichloro-2,2-bis(4-ethylphenyl)ethane.
Ethyl parathion	Parathion	*O*,*O*-diethyl *O*-(*p*-nitrophenyl)phosphorothioate.
Fenvalerate	Pydrin	cyano(3-phenoxyphenyl)methyl 4-chloro-alpha-(1-methylethyl)benzeneacetate.
Malathion	Malathion	*O*,*O*-dimethyl *S*-(1,2-dicarbethoxyethyl)phosphorodithioate; or *O*,*O*-dimethyl phosphorodithioate of diethyl mercaptosuccinate.
Methidathion	Supracide	*O*,*O*-dimethyl *S*-(2,3-dihydro-5-methoxy-2-oxo-1,3,4-thiadiazol-3-ylmethyl) phosphorodithioate.
Methomyl	Lannate, Nurdin	*S*-methyl-*N*-(methylcarbamoyloxy)thioacetimidate.
Methyl parathion	Methyl parathion	*O*,*O*-diethyl *O*-(*p*-nitrophenyl) phosphorothioate.
Mevinphos	Phosdrin	2-carbomethoxy-1-methylvinyl dimethyl phosphate, *E* isomer.
Permethrin	Ambush, Pounce	3-(phenoxyphenyl)methyl (∓)-cis, trans-3-(2,2-dichloroethenyl)-2,2-dimethyl cyclopropanecarboxylate (approx 60% trans, 40% cis isomers).
Sulprofos	Bolstar	O-ethyl O-[4-(methylthio)phenyl]*S*-propyl phosphorodithioate.

to water samples in April 1980 were adjusted for degradation if they had not been extracted within approximately 1 week after sampling.

Analytical Quality Assurance Study. A limited number of 4-L runoff water samples were split into four subsamples with three subsamples of each being sent to other laboratories for comparative pesticide analysis. One subsample was analyzed in our laboratory, and the others were sent to three cooperating laboratories, that is, the Food and Drug Administration Laboratory in Los Angeles, the U.S. Geological Survey Laboratory in Denver, and the Environmental Protection Agency Laboratory in Bay St. Louis, Miss. Water samples were shipped to the cooperating laboratories in 1-L glass bottles packed in cardboard and styrofoam containers and mailed by Express Mail or Federal Express with overnight arrival in the laboratory city. The samples were precooled and packed with "cold-paks" and arrived at the cooperating laboratory at temperatures of less than 10°C; however, some samples were lost in transit due to breakage of the glass bottles.

Table 4. — *Extracting solvents and gas-liquid chromatograph (GLC) detectors used for pesticide analysis in runoff waters and minimum detectable pesticide levels based on 500-ml water samples, 5-ml final volumes, and 5-µl injections*

	Extracting solvent			GLC detector			Minimum detectable
	Hexane	CH_2Cl_2	$CHCl_3$	FPD[1]		EC[2]	
				P	S		
							P/b
Cycloate	X				X		0.6
DCPA	X					X	.01
Dinitramine	X					X	.03
EPTC	X				X		.5
Prometryn	X				X		.8
Trifluralin	X					X	.005
Azinphosmethyl	X			X			.5
Chlorpyrifos	X			X			.1
Diazinon	X			X			.03
Endosulfan	X					X	
Ethylan	X					X	
Ethyl parathion	X			X			.04
Fenvalerate	X					X	.04
Malathion	X			X			.24
Methidathion	X			X			.06
Methomyl		X			X		.6
Methyl parathion	X			X			.03
Mevinphos			X	X			.1
Permethrin		X				X	.7
Sulprofos		X		X			.02

[1]Flame photometric detector with phosphorus (P) or sulfur (S) sensitive filter.
[2]Electron capture detector.

The procedures for the analysis of pesticides were similar in each laboratory with the exception that laboratory III used 20 percent acetone in methylene chloride for extraction of all pesticides instead of the solvents listed in table 4.

Sediment Characterization and Partitioning of Pesticides into Sediment. The partitioning of pesticides between the sediment and water in runoff is important in pesticide transport from treated areas. A few 4-L water samples were separated into sediment and water phases to determine the partitioning of several pesticides between the water and sediment and to characterize the sediment in terms of particle size distribution and organic matter content. The sediment was separated from the water in a millipore apparatus using Whatman GF/C glass fiber filters. Pesticides were extracted from the water phase as previously described and from the sediment by extraction with a mixture of hexane: acetone simliar to the soil extraction procedure. Particle size distribution in sediment was determined using a pipette procedure similar to that described by Guy *(1969)*. Organic carbon content of the sediment was determined by a dry combustion procedure using a modified Coleman N analyzer.

Data Calculations

Runoff Volumes and Pesticide Losses. Runoff water volumes were calculated from hydrographs, obtained with water stage recorders, by integrating the area under the hydrograph using the trapezoidal rule. Most of the irrigations resulted in multi-peak runoff hydrographs. The total amounts of pesticides removed from treated fields in runoff water were calculated from flow volumes and pesticide concentrations. This was done by integrating the flux of the pesticide calculated from the product of the pesticide concentration and the waterflow at the time discrete samples were taken. Fluxes of the pesticides were calculated from flow volumes over a time period equivalent to the time between individual samplings. The pesticide loss (L), in grams per hectare, was calculated with the following equation:

$$L = \left[(C_{x_1})(V_1) + (C_{x_2})(V_2) + - - - C_{x_n}V_n\right] 10^{-6}/\text{area}$$

Where C is pesticide concentration, in micrograms per liter (µg/L); V is runoff volume, in liters; and area is in hectares. The runoff volume, such as V_1, represents the runoff volume for time period t_0 and t_1 for sample x_1, which was taken halfway between t_0 and t_1, likewise for samples represented with subscript 2 to subscript n.

The integration method was used whenever 10 or more samples were taken and a complete hydrograph for the runoff event was obtained. When a smaller number of

water samples was taken (9 or less per runoff event), pesticide losses in runoff water usually were calculated by multiplying the average concentration in the samples by the total runoff volume. Where the water stage recorder malfunctioned and produced an incomplete hydrograph, total runoff volumes were estimated from the partial record of flow and/or comparison with previous irrigations on the same field. Concentrations of pesticides in samples taken during these irrigations were averaged and multiplied by the estimated total runoff volume to calculate pesticide losses during the event. Mean pesticide concentrations for each runoff event were calculated from the total amount of pesticide in runoff water divided by the total volume of runoff. Sediment losses and mean concentrations in runoff were calculated in the same way.

Statistical Correlations. The relationship between pesticides in runoff and several independent variables was determined by simple linear regression analysis. Three dependent variables reflecting pesticides in runoff, that is, concentrations, amounts, and percent of the total applied in runoff, were correlated with the following five independent variables: (1) time elapsed since the last pesticide application, (2) accumulative water applied since the last pesticide application, (3) runoff volume, (4) sediment in the runoff water, and (5) soil pesticide content in the 0- to 1-cm depth. The correlation analyses were carried out by individual chemicals, by crops and chemicals, and by various groupings of chemicals based on use, such as herbicides, insecticides, and organophosphate insecticides. Regressions were determined for first irrigations after pesticide applications, for subsequent irrigations, and for all irrigations combined. The general statistical analysis procedure was similar to that described by Zison (*1980*). Where obvious nonlinearity was observed, $\log_{10}$ transforms of the data were used in the correlation.

In one analysis, multiple regression was used to determine the combined effect of time and cumulative water applied since the last pesticide application on pesticide runoff. In all correlations, the "zero day events," when pesticides were aerially applied while irrigation water was on the field, were omitted from the correlations for the applied pesticide. When concentrations of applied pesticides were nondetectable in runoff water, a value equal to 0.2 times the minimum detectable level was used as the observed concentration for correlation purposes.

Soil pesticide concentrations and amounts in the 0- to 1-cm soil depth from samples taken prior to selected irrigations are shown in appendix tables 1 to 6. The data are tabulated by fields 1 to 10 in the same chronological order as the data on pesticides in runoff water samples in tables 5 to 22. In addition to correlating the runoff of pesticides with the concentration of pesticides in soil, the apparent persistence of 10 of the pesticides was determined by linear regression analysis of the relationship between concentration and amounts of pesticides in soil and the time elapsed since the last pesticide application. Log_{10} transforms of the concentrations and amounts were also used to estimate first-order decay constants for the pesticides during the growing season.

Pesticide Runoff

Tables 5 to 22 show pesticides in irrigation runoff water from fields planted to cotton, sugarbeets, lettuce, cantaloupes, onions, and alfalfa. The data are presented chronologically by irrigation runoff events and crop years for each field. Most of the runoff data were obtained from fields 1 to 7 on which a total of seven cotton crops, three sugarbeet, three alfalfa, and two lettuce crops were grown between 1978 and 1982. Table 23 provides a summary of total seasonal losses in irrigation runoff water for those pesticides for which sufficient data were obtained to calculate seasonal losses. Data in table 23 are useful in making general comparisons between pesticides, but a closer examination of individual irrigation events in tables 5 to 22 is necessary to determine water quality effects and determine the soil, crop, or water management practices that may influence amounts of pesticides in irrigation runoff water.

Text continues on p. 30.

Table 5. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 1, 1979)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1979	Percent canopy cover	Runoff dates in 1979	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Prometryn	[2]2.24	4/17	0	4/22-27	26	13.1	5	5.8	92	14	18	0.80	0.80
	—	—	—	5/6-10	16.3	5.7	20	3.4	7.3	5.4	3.1	—	.14
	—	—	—	6/12-14	16.2	5.0	56	4.2	15.4	11.2	5.6	—	.25
	—	—	—	7/6-11	19	10.4	80	1.8	7.3	3.9	4.1	—	.18
	[3].90	7/19-24	40	7/24-26	14.2	4.0	[4]5	32	1,408	180	72	8.0	2.3
	—	—	—	8/6-9	15.3	[5](2.4)	18	25	365	40	(9.5)	—	.30
	—	—	—	8/22-24	13.7	3.6	34	5.1	119	26	9.3	—	.30
	—	—	—	9/4-7	15.3	2.2	47	3.1	241	45	7.9	—	.25
	—	—	—	9/19-21	15.2	(4.6)	63	13	185	32	14.9	—	.47
	—	—	—	10/2-4	15.2	4.0	75	3.4	577	32	12.8	—	.41
Totals	**3.14**										**157**		**5.0**
Dinitramine	[2]0.75	4/17	0	4/22-27	26	13.1	5	.1	4.0	1.5	1.9	.25	.25
	—	—	—	5/6-10	16.3	5.7	20	.3	1.3	.7	.4	—	.05
	—	—	—	6/12-14	16.2	5.0	56	N.D.	.8	.6	.3	—	.04
	—	—	—	7/6-11	19.0	10.4	80	N.D.	1.0	.4	.4	—	.05
	[3]0.56	7/19-24	40	7/24-26	14.2	4.0	5	9.8	22	15.0	6.0	1.1	.46
	—	—	—	8/6-9	15.3	(2.4)	18	5.0	16	7.0	(1.7)	—	.13
	—	—	—	8/22-24	13.7	3.6	34	1.0	8.2	5.6	2.0	—	.15
	—	—	—	9/4-7	15.3	2.2	47	.2	1.4	.7	.2	—	.02
	—	—	—	9/19-21	15.2	(4.6)	63	2.1	15	4.8	(2.2)	—	.17
	—	—	—	10/2-4	15.2	4.0	75	.2	34	5.5	2.2	—	.17
Totals	**1.31**										**17.3**		**1.32**

Table 5. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 1, 1979) (continued)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1979	Percent canopy cover	Runoff dates in 1979	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Chlorpyrifos	.56	7/18	40	7/24-26	14.2	4.0	[4]6	N.D.	.3	.03	.01	.002	.002
	.39	8/1	80	8/6-9	15.3	(2.4)	5	—	N.D.< .02	—	—	—	—
	.39	8/9	95										
	.34	8/15	95	8/22-24	13.7	3.6	[6]7	.36	1.3	.50	.18	.025	.011
	—	—	—	9/4-7	15.3	2.2	20	.09	.16	.14	.03	—	.002
	—	—	—	9/19-21	15.2	(4.6)	36	.04	.12	.09	(.04)	—	.004
	—	—	—	10/2-4	15.2	4.0	48	N.D.	.13	.08	.03	—	.002
Totals	**1.68**										**.29**		**.02**
Azinphosmethyl	0.52	7/12	40	7/24-26	14.2	4.0	[4]12	—	N.D.< .01	—	—	—	—
Permethrin	.11	7/18	40	7/24-26	14.2	4.0	[4]6	—	N.D.< .01	—	—	—	—
	.12	7/27	70										
	.12	8/1	80	8/6-9	15.3	(2.4)	5	N.D.	.86	.08	(0.02)	.008	.006
	.16	8/14	95										
	.20	[7]8/23	98	8/22-24	13.7	3.6	0	N.D.	71	3.1	1.1	.21	.13
Totals	**0.71**										**[8]1.12**		**0.16**
Fenvalerate	.19	9/19	98	9/19-21	15.2	(4.6)	1	.06	.25	.13	(.06)	.03	.03
	.19	9/26	98										
	.19	[7]10/4	98	10/2-4	15.2	4.0	0	.01	14	1.3	.52	.14	.09
	—	—	—	[9]3/15-18	28	6.1	[10]154	—	N.D.< .04	—	—	—	—
Totals	**.57**										**[11].58**		**.10**

[1]Mean concentratrion equals amount of pesticide divided by volume of runoff water. N.D. = not detectable at the levels indicated.
[2]Herbicides applied preplant to top of beds and incorporated 2-3 inches deep.
[3]Herbicides applied by spraying over entire ground surface and mulched-in with a Lilliston rig. Applications made over a 5-day period 7/19-24 with 0.86 cm rainfall on 7/20.
[4]Rainfall, 1.2 cm between applications and first runoff on 7/24-26.
[5]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.
[6]Rainfall, 1.5 cm between chlorpyrifos application and runoff on 8/22-24.
[7]Insecticides applied by airplane while irrigations were in progress.
[8]98 percent of the total permethrin runoff loss (1.1 of 1.12 g/ha) occurred immediately following its application during the irrigation event on 8/23/79.
[9]1980
[10]Flood irrigation prior to planting next cotton crop; prometryn and dinitramine also not detectable.
[11]90 percent of the total fenvalerate loss (.52 of 0.58 g/ha) occurred during the irrigation event in which fenvalerate was applied while irrigation was in progress on 10/4/79.

Table 6. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 1, 1980)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1980	Percent canopy cover	Runoff dates in 1980	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Prometryn	[2]0.3	4/12	< 5	4/14-18	17.7	[3](4.8)	2	N.D.	61	7.1	(3.4)	1.1	1.1
	—	—	—	5/27-29	19.0	3.1	45	N.D.	42	14.8	4.6	—	1.5
	—	—	—	6/23-27	12.5	2.9	72	N.D.	13	4.8	1.4	—	.50
	—	—	—	7/18-21	21.1	3.2	97	N.D.	11	0.3	0.1	—	.03
	[4]1.3	8/1	55	8/5-8	17.1	(2.0)	4	7.5	82	37.5	(7.5)	.6	.50
	—	—	—	8/18/21	15.2	3.4	17	2.7	39	11.8	4.0	—	.25
	—	—	—	9/2-4	12.1	1.3	32	1.7	10	4.6	.6	—	.04
	—	—	—	9/16-18	12.2	(2.2)	46	N.D.	[5]2.4	—	—	—	—
	—	—	—	9/30-10/1	12.2	2.7	59	—	N.D.< .8	—	—	—	—
	—	—	—	[6]2/20-24	27.0	4.3	[7]203	N.D.	137	4.4	1.9	—	.12
Totals	**1.6**										**23.5**		**1.47**
DCPA	[2]3.4	4/12	< 5	4/14-18	17.7	(4.8)	2	6.4	35	21.5	(10.3)	.3	.3
	—	—	—	5/27-29	19.0	3.1	45	15	74	22.0	6.8	—	.2
	—	—	—	6/23-27	12.5	2.9	72	2.4	27	15.5	4.5	—	.13
	—	—	—	7/18-21	21.1	3.2	97	.2	15	10.3	3.3	—	.10
	[4]4.2	8/1	55	8/5-8	17.1	(2.0)	4	35	189	153	(30.5)	.73	.40
	—	—	—	8/18-21	15.2	3.4	17	35	173	83	28.3	—	.37
	—	—	—	9/2-4	12.2	1.3	32	33	58	48	6.3	—	.08
	—	—	—	9/16-18	12.2	(2.2)	46	5.7	9	7.3	(1.6)	—	.02
	—	—	—	9/30-10/1	12.2	2.7	59	1.8	3	2.3	.6	—	.01
	—	—	—	[6]2/20-24	27.0	4.3	[7]203	.5	2	1	.4	—	.005
Totals	**7.6**										**92.6**		**1.22**
Methomyl	.4	5/17	25	5/27-29	19.0	3.1	9	2.2	59	21	6.5	1.6	1.6
	—	—	—	6/23-27	12.5	2.9	39	N.D.	1.5	1.0	.29	—	.07
	—	—	—	7/18-21	21.1	3.2	61	N.D.	1.6	.34	.11	—	.03
	—	—	—	8/5-8	17.1	(2.0)	79	—	N.D.< .6	—	—	—	—
Totals	**.4**										**6.9**		**1.73**
Fenvalerate	.11	8/3	55	8/5-8	17.1	(2.0)	2	.05	.14	.10	(.02)	.02	.02
	—	—	—	8/18-21	15.2	3.4	14	N.D.	.62	.23	.04	—	.07
	.16	8/23	80	9/2-4	12.1	1.3	10	N.D.	1.2	.39	.05	.03	.02
	—	—	—	9/16-18	12.2	(2.2)	24	—	N.D.< .01	—	—	—	—
	—	—	—	[6]2/20	27.0	4.3	[7]181	—	N.D.< .01	—	—	—	—
Totals	**.27**										**.15**		**.05**
Permethrin	.17	9/1	95	9/2-4	12.1	1.3	1	—	N.D.< .7	—	—	—	—
	.20	9/15	95	9/16-18	12.2	(2.2)	1	—	N.D.< .7	—	—	—	—
	.14	9/24	98	9/30-10/1	12.2	2.7	6	—	N.D.< .7	—	—	—	—
Totals	**.51**										**N.D.**		

Table 6. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 1, 1980) (continued)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1980	Percent canopy cover	Runoff dates in 1980	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Chlorpyrifos	.42	9/1	95	9/2-4	12.1	1.3	1	N.D.	3.6	1.0	.13	.03	.03
	.28	9/15	95	9/16-18	12.2	(2.2)	1	.9	3.1	1.8	(.4)	.14	.06
	—	—	—	9/30-10/1	12.2	2.7	15	.2	.4	.3	.08	—	.01
	—	—	—	[6]2/20-24	27.0	4.3	[7]158	—	N.D.< .1	—	—	—	—
Totals	**.70**										**.61**		**.09**

[1]Mean concentration equals amount of pesticide in runoff divided by volume of runoff water. N.D. = not detectable at the levels indicated.
[2]Herbicides applied to top of beds.
[3]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.
[4]Herbicides applied by spraying over the entire ground surface with a Lilliston rig.
[5]Prometryn detected in 1 sample only.
[6]1981.
[7]Flood irrigation prior to planting next cotton crop in March 1981.

Table 7. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 1, 1981)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Prometryn	[2]0.3	3/25-27	0	3/28-4/1	18.3	5.3	2	N.D.	24	10.9	5.8	1.9	1.9
	—	—	—	4/28-30	12.5	3.0	33	N.D.	60	6.3	1.9	—	.6
	—	—	—	5/21-23	12.2	[3](3.0)	56	1.1	2.1	1.5	(.44)	—	.15
	—	—	—	6/11-13	12.9	3.8	78	N.D.	3.6	1.1	.4	—	.13
	[4]1.3	6/25	—	6/26-28	12.2	4.0	1	24	77	33	13.3	1.02	.83
	—	—	—	7/7-9	10.8	.9	12	N.D.	30	20.5	1.8	—	.11
	—	—	—	7/16-18	10.7	1.8	21	2.3	16	6.2	1.12	—	.07
	—	—	—	7/27-28	10.4	1.8	32	4.4	9.3	6.1	1.07	—	.07
	—	—	—	8/4-7	9.7	1.8	40	N.D.	8.9	3.3	.61	—	.04
	—	—	—	8/18-19	4.7	1.8	54	N.D.	13.5	3.9	.71	—	.04
	—	—	—	8/31-9/3	11.0	.7	67	—	N.D.< 0.8	—	—	—	—
	—	—	—	9/14-17	10.0	2.6	82	—	N.D.< 0.8	—	—	—	—
Totals	**1.6**										**27.15**		**1.70**
DCPA	[2]3.4	3/25-27	0	3/28-4/1	18.3	5.3	2	21	160	46.8	24.8	.73	.73
	—	—	—	4/28-30	12.5	3.0	33	15	125	52.3	15.7	—	.46
	—	—	—	5/21-23	12.2	(3.0)	56	8	19	13.0	(3.9)	—	.11
	—	—	—	6/11-13	12.9	3.8	78	3	8	5.0	1.9	—	.06
	—	—	—	6/26-28	12.2	4.0	93	1.3	5	1.9	.74	—	.02
	—	—	—	7/7-9	10.8	.9	104	.7	4.2	1.8	.16	—	.005
	—	—	—	7/16-18	10.7	1.8	113	.6	1.9	.8	.14	—	.004
	—	—	—	7/27-28	10.4	1.8	124	.4	.7	.6	.10	—	.003
	—	—	—	8/4-7	9.7	1.8	132	N.D.	1.0	.4	.08	—	.002

Table 7. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 1, 1981) (continued)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
	—	—	—	8/18-19	4.7	1.8	146	.2	1.9	.7	.13	—	.004
	—	—	—	8/31-9/3	11.0	.7	159	.3	.6	.4	.03	—	.001
	—	—	—	9/14-17	10.0	2.6	173	.07	.2	.2	.04	—	.001
Totals	**3.4**										**47.72**		**1.40**
Trifluralin	[4]1.1	6/25	30	6/26-28	12.2	4.0	1	2.9	18	5.0	2.0	.18	.18
	—	—	—	7/7-9	10.8	.9	12	1.0	10	4.1	.36	—	.03
	—	—	—	7/16-18	10.7	1.8	21	1.4	6.8	2.8	.50	—	.05
	—	—	—	7/27-28	10.4	1.8	32	.8	1.8	1.4	.24	—	.02
	—	—	—	8/4-7	9.7	1.8	40	.3	1.4	.6	.11	—	.01
	—	—	—	8/18-19	4.7	1.8	54	—	N.D.< .01	—	—	—	—
Totals	**1.1**										**3.21**		**.29**
Chlorpyrifos	0.28	7/15	60	7/16-18	10.7	1.8	1	1.4	22	3.3	.59	.21	.21
	.32	7/22	75	7/27-28	10.4	1.8	5	.3	.7	.5	.09	.03	.02
	.32	7/29	85										
	.56	[5]8/5	95	8/4-7	9.7	1.8	0	N.D.	480	22.4	4.1	.47	.28
	.32	8/18	95	8/18-19	4.7	1.8	.2	2.2	13	3.9	.7	.22	.04
	.32	8/25	95										
	.32	8/31	95	8/31-9/3	11.0	.7	1	.9	6.0	1.3	.09	.01	.004
	—	—	—	9/14-17	10.0	2.6	15	.5	3.5	1.5	.39	—	.016
Totals	**2.44**										**5.96**		**.24**
Permethrin	.20	7/15	60	7/16-18	10.7	1.8	1	N.D.	7.0	.7	.13	.07	.07
	.20	7/22	75	7/27-28	10.4	1.8	5	—	N.D.< .7	—	—	—	—
	.14	7/29	85	8/4-7	9.7	1.8	6	—	N.D.< .7	—	—	—	—
	.16	8/11	95										
	.16	8/18	95	8/18-19	4.7	1.8	.2	.7	3.9	.9	.17	.05	.02
	.16	8/25	95										
	.20	8/31	95	8/31-9/3	11.0	.7	1	.4	7.3	.6	.04	.01	.003
	—	—	—	9/14-17	10.0	2.6	15	—	*N.D.*< .7	—	—	—	—
Totals	**1.22**										**.34**		**.028**
Fenvalerate	.11	[5]8/5	95	8/4-7	9.7	1.8	0	N.D.	120	5.1	0.93	.85	.85
	—	—	—	8/18-19	4 .7	1.8	13	N.D.	.2	.02	.003	—	.003
	—	—	—	8/31-9/3	11.0	.7	26	N.D.	.1	.01	< .001	—	< .001
	.19	9/5	95										
	.19	9/12	95	9/14-17	10	2.6	2	.2	.5	.35	.09	.05	.02
Totals	**0.49**										**1.024**		**.21**
Malathion	1.31	9/12	95	9/14-17	10	2.6	2	—	N.D.< .24	—	—	—	—

[1]Mean concentration equals amount of pesticide divided by the volume of runoff water. N.D. = not detectable at the levels indicated.
[2]Herbicides applied to top of beds.
[3]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water stage recorder.
[4]Herbicides applied by spraying over the entire ground surface with a Lilliston rig.
[5]Applied by airplane while irrigation was in progress; 69 percent of the total chlorpyrifos and 91 percent of the total fenvalerate loss occurred during this irrigation.

Table 8. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 2, 1980)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1980	Percent canopy cover	Runoff dates in 1980	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Prometryn	[2]1.3	7/7-8	50	7/12-13	14.3	[3](0.6)	5	13	385	163	(9.3)	0.71	0.71
	—	—	—	7/25-27	11.6	.4	19	12	81	37	1.6	—	.12
	—	—	—	[4]8/24-26	13.4	(3.1)	48	2	9	4.2	(1.3)	—	.10
	—	—	—	9/13-16	24.3	2.4	68	—	N.D.< .8	—	—	—	—
	—	—	—	[5]4/6-8/1	[6]10.9	1.3	273	N.D.	9	1.7	.2	—	.02
	—	—	—	[5]4/22/1	6.5	(.8)	289	—	N.D.< .8	—	—	—	—
Totals	**1.3**										**12.4**		**.75**
Trifluralin	[2].96	7/7-8	50	7/12-13	14.3	(.57)	5	3	19	10.7	(.61)	.06	.06
	—	—	—	7/25-27	11.6	.43	19	1	8	5.6	.24	—	.03
	—	—	—	[4]8/24-26	13.4	(3.1)	48	.3	1.5	.9	(.29)	—	.03
	—	—	—	9/13-16	24.3	2.4	68	.1	1.0	.5	.10	—	.01
	—	—	—	9/29-30	9.1	3.4	84	.2	.5	.41	.14	—	.01
Totals	**.96**										**1.38**		**.14**
Methidathion	.56	8/15	80	8/24-26	13.4	(3.1)	9	.7	56	6.1	(1.9)	.34	.34
	.56	9/1	95	9/13-16	24.3	2.4	12	.3	3	1.8	.4	.07	.04
	—	—	—	9/29-30	9.1	3.4	28	—	N.D.< .06	—	—	—	
Totals	**1.12**										**2.3**		**0.21**
Fenvalerate	.15	8/15	80										
	.19	[7]8/24	85	8/24-26	13.4	(3.1)	0	.3	133	2.2	[8](.67)	.35	.20
	.15	9/1	95	9/13-16	24.3	2.4	12	N.D.	5	.4	.10	.07	.02
	.19	9/17	95										
	.17	9/25	95	[9]9/29-30	9.1	3.4	4	.4	2.4	.8	.27	.08	.03
	.19	10/4	95										
	.19	10/19	95	[5]4/6-8/1	[6]10.9	1.3	169	N.D.	.3	.1	.01	—	.001
	—	—	—	[5]4/22/1	6.5	(0.8)	185	.06	.13	.1	.01	—	.001
	—	—	—	[5]5/2-4/1	5.8	2.2	195	—	N.D.< .04	—	—	—	—
Totals	**1.23**										**1.06**		**.09**
Chlorpyrifos	.96	9/17	95	[9]9/29-30	9.1	3.4	12	.06	1.6	.7	.23	.02	.02
Totals	**.96**										**.23**		**.02**
Permethrin	.10	8/5	75	[4]8/24-26	13.4	(3.1)	19	—	N.D.< .7	—	—	—	—

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.

[2]Herbicides applied at midseason by spraying over the entire ground surface with a Lilliston rig.

[3]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.

[4]Also irrigated 8/9-11/80, but no runoff samples were obtained.

[5]1981.

[6]First furrow irrigation of melon crop following cotton. Melons were planted in January 1981 and sprinkler irrigated in February.

[7]Applied by airplane while irrigation was in progress.

[8]75 percent of the fenvalerate loss during this irrigation and 63 percent of the total seasonal loss (0.5 g/ha) occurred within 5 hr. after the aerial application.

[9]Last irrigation of cotton before harvest.

Table 9. — *Pesticides in irrigation runoff water from a 28-ha lettuce field irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 2, planted 10/9/81-harvested 1/82)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Ethyl parathion	0.40	10/14,20	1										
	.43	10/26,27	10	[2]11/24-26	10.5	1.0	28	1.1	1.7	1.3	0.13	0.03	0.015
	—	—	—	12/8-9	3.6	.8	42	N.D.	.6	.6	.05	—	.006
	—	—	—	12/26-29	8.4	1.1	60	—	N.D.< .01	—	—	—	—
Totals	**.83**										**.18**		**.02**
Methyl parathion	.20	10/14,20	1										
	.22	10/26,27	10	[2]11/24-26	10.5	1.0	28	.07	.22	.10	.01	.005	.002
	—	—	—	12/8-9	3.6	.8	42	N.D.	.05	.04	.003	—	.001
	—	—	—	12/26-29	8.4	1.1	60	—	N.D.< .01	—	—	—	—
Totals	**.42**										**.013**		**.003**
Methomyl	.58	10/26,27	10										
	.85	11/14	20	11/24-26	10.5	1.0	10	18	74	41	4.0	.47	.28
	1.12	12/2	35	12/8-9	3.6	.8	6	46	191	119	10.0	.89	.39
	.86	12/12,15	50	12/26-29	8.4	1.1	14	3	34	22	2.3	.27	.07
Totals	**3.41**										**16.3**		**.48**
Endosulfan	.84	11/14	20	11/24-26	[3]10.5	1.0	10	4.8	9.3	6.2	.61	.07	.07
	—	—	—	12/8-9	[3]3.6	.8	24	2.2	4.9	3.2	.27	.03	.03
	.82	12/12,15	50	12/26-29	8.4	1.1	14	6	30	21.7	2.3	.28	.14
Totals	**1.66**										**3.18**		**.19**

[1]Mean concentration equals amount of pesticide in runoff divided by volume of runoff water. N.D. = not detectable.

[2]First runoff after second ethyl and methyl parathion applications; also furrow irrigated 10/14-15/81 and 10/23-25/81 with no runoff samples taken.

[3]Both irrigations are first irrigations after endosulfan application; east half of field irrigated 11/24-26/81; west half of field irrigated 12/8-9/81.

Table 10. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 3, 1978)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1978	Percent canopy cover	Runoff dates in 1978	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Methidathion	0.56	7/2	60	7/9-10	7.8	[2](1.6)	7	1.8	23	10.2	(1.63)	0.28	0.28
	.56	7/18	65	7/19-20	9.3	.9	1	No samples taken					
	—	—	—	7/30-8/1	16.0	2.2	12	.1	1.4	.5	.1	—	.01
	—	—	—	8/16-17	12.5	1.0	29	.01	.2	.1	.01	—	.001
	—	—	—	9/1-2	11.5	2.0	45	.05	.2	.1	.02	—	.002
	—	—	—	9/12-13	10.8	1.7	56	—	N.D.< .01	—	—	—	—
Totals	**1.12**										**1.76**		**.16**
Malathion	1.12	8/3	75	8/16-17	12.5	1.0	13	.02	.2	.04	.004	.0003	.0003
Sulprofos	1.43	9/11	95	[3]9/12-13	10.8	1.7	1	.02	.32	.13	.02	.001	.001
	1.68	9/29	95										
	1.44	10/8	95	[4]2/21/79	15.9	2.9	136	—	N.D.< .01	—	—	—	—
Fenvalerate	.10	8/3	75	8/16-17	12.5	1.0	13	—	N.D.< 1	—	—	—	—
Permethrin	.17	8/13	80	8/16-17	12.5	1.0	3	—	N.D.< .16	—	—	—	—
	.17	8/24	85	9/1-2	11.5	2.0	8	—	N.D.< .16	—	—	—	—
	.17	9/3	90	9/12-13	10.8	1.7	9	—	N.D.< .16	—	—	—	—

[1]Mean concentration equals amount of pesticide in runoff divided by volume of runoff water. N.D. = not detectable.
[2]Runoff values in parentheses were estimated.
[3]Last irrigation to 1978 cotton crop.
[4]First furrow irrigation to onions in 1979 following cotton.

Table 11. — *Pesticides in irrigation runoff water from a 14-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 3, 1979)*

Pesticide application				Irrigation runoff				Pesticides in runoff						
								Concentration[1]						
Chemical	Rate	Date in 1979	Percent canopy cover	Runoff dates in 1979	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Methidathion	0.48	7/21	85										
	.54	[2]7/29	90	7/28-29	17.6	[3](3.2)	0	0.8	473	64	[4](20.4)	[5]3.8	2.0
	—	—	—	8/8-10	26.8	(4.0)	10		Not sampled		—	—	—
	—	—	—	8/29-31	16.9	1.6	31	.1	.7	.5	.08	—	.008
	—	—	—	9/4-5	13.4	3.0	37		Not sampled		—	—	—
	—	—	—	9/13-16	30.1	9.8	46	—	[6]N.D.< .06	—	—	—	—
Totals	**1.02**										**20.48**		**2.0**
Fenvalerate	.08	7/21	85										
	.08	[2]7/29	90	7/28-29	17.6	(3.2)	0	N.D.	15.2	1.6	[4](.50)	[5].6	.3
	.19	[2]8/8	95	8/8-10	26.8	(4.0)	10		Not sampled		—	—	—
	—	—	—	8/29-31	16.9	1.6	21	—	N.D.< .01	—	—	—	—
	.19	9/10	95	9/13-16	30.1	9.8	3	—	[6]N.D.< .01	—	—	—	—
Totals	**.54**										**.50**		**.09**
Permethrin	.20	8/15	95										
	.20	8/21	95	8/29-31	16.9	1.6	8	1.4	5.8	3.4	.54	.14	.14
	.20	9/1	95	9/4	13.4	3.0	14		Not sampled		—	—	—
	—	—	—	9/13-16	30.1	9.8	12	—	[6]N.D.< .7	—	—	—	—
Methomyl	.17	[2]8/8	95	8/8-10	26.8	(4.0)	10		Not sampled		—	—	—
	—	—	—	8/29-31	16.9	1.6	21	—	N.D.< .6	—	—	—	—

[1]Mean concentration equals amount of pesticide in runoff divided by volume of runoff water. N.D. = not detectable.
[2]Insecticides applied by plane while irrigation was in progress.
[3]Runoff values in parentheses were estimated.
[4]99 percent of the methidathion and all of the fenvalerate loss occurred immediately following their application during the irrigation event.
[5]Percentage of insecticides applied on 7/29/79 during the irrigation.
[6]Also not detectable on 1/8/80 and subsequent irrigations on wheat.

Table 12. — *Pesticides in irrigation runoff water from a 28-ha lettuce field irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 3, lettuce planted 10/6/80, harvested 1/81)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1980	Percent canopy cover	Runoff dates in 1980	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Ethyl parathion	0.84	10/15	1										
	[2].84	10/21-22	<5	10/22-24	13.4	2.9	1	31	77	50	14.2	0.85	0.85
	.84	10/31	6										
	.84	11/2	6	11/14-15	10.4	3.5	12	5	19	11	3.8	.23	.01
	.84	11/17	10	12/10-12	11.4	[3](2.2)	23	.04	5.3	1.7	(.37)	.05	.01
	—	—	—	12/30-31	[4]1.9	[5].01	43	N.D.	.1	.1	NIL	—	—
	—	—	—	[6]2/21/81	[7]18.0	3.3	96	N.D.	[8].02	< .01	NIL	—	—
	—	—	—	[6]3/29/81	[9]21	5.5	132	N.D.	[10].02	< .01	NIL	—	—
	—	—	—	[6]4/16/81	3.7	.5	150	—	N.D.< .01	—	—	—	—
Totals	**4.20**										**18.4**		**.44**
Methyl parathion	.42	10.15	1										
	[2].42	10/21-22	< 5	10/22-24	13.4	2.9	1	12	24	18	5.2	.62	.62
	.42	10/31	6										
	.42	11/2	6	11/14-15	10.4	3.5	12	2	8	4.0	1.4	.17	.08
	.42	11/17	10	12/10-12	11.4	(2.2)	23	.02	1.5	.4	(.09)	.02	.004
	—	—	—	12/30-31	[4]1.9	[5].01	43	N.D.	.05	.02	NIL	—	—
	—	—	—	[6]2/21/81	[7]18.0	3.3	96	—	N.D.< .01	—	—	—	—
Totals	**2.1**										**6.7**		**.32**
Methomyl	[2].84	10/21-22	< 5	10/22-24	13.4	2.9	1	34	50	45	13.1	1.56	1.56
	.84	10/31	6										
	.84	11/2	6	11/14-15	10.4	3.5	12	6	36	19	6.8	.40	.27
	[11].64	11/29	25	12/10-12	11.4	(2.2)	11	1	7	4.0	(.9)	.14	.03
	—	—	—	12/30-31	[4]1.9	[5]0.01	31	16	34	23	.02	—	.008
	—	—	—	[6]2/21/81	[7]18.0	3.3	84	N.D.	1.5	.8	.26	—	.008
	—	—	—	[6]3/29/81	[9]21.0	5.5	120	—	N.D.< .6	—	—	—	—
Totals	**3.6**										**21.08**		**.67**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.
[2]East half of field treated 10/21/80; west half, 10/22/80.
[3]Runoff values in parentheses were estimated.
[4]Only east half of field irrigated lightly.
[5]Estimated runoff based on a very low rate of < 0.1 ft^3/sec for approximately 24 hr.
[6]1981.
[7]Flood irrigation after lettuce prior to planting cotton.
[8]Detectable in only 1 of 4 samples.
[9]First furrow irrigation to cotton after planting.
[10]Detectable in only 2 of 13 samples.
[11]Applied by ground rig to top of beds.

Table 13. — *Pesticides in irrigation runoff water from a 28-ha cottonfield irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 3, 1981)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last Irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
DCPA	[2]3.6	3/27	0	3/29-4/3	21	[3](5.5)	2	5	19	10.5	(5.8)	0.16	0.16
	—	—	—	4/16-17	3.7	(.5)	20	1.5	2.8	2.2	(.1)	—	.003
	—	[4]6/1	—	6/10-11	13.4	1.4	75	34	135	111	15.5	—	.43
	—	—	—	6/24-25	13.5	2.2	89	24	98	47	10.4	—	.29
	—	—	—	7/9-10	12.2	(2.5)	104	11	106	46	(11.4)	—	.32
	—	—	—	7/21-22	12.2	(3.3)	116	5	11	8.2	(2.7)	—	.08
	—	—	—	7/31-8/1	12.1	(2.0)	126	1.0	26	10	(2.0)	—	.06
	—	—	—	8/11-12	5.0	(.5)	137	3	8.5	5.8	(.3)	—	.01
	—	—	—	8/25-26	13.0	(2.0)	151	.4	5.8	2.8	(.6)	—	.02
	—	—	—	9/3-5	10.6	(1.3)	160	.1	1.6	.9	(.1)	—	.003
	—	—	—	[5]9/17-18	13.1	(2.1)	174	1.0	2.4	1..6	(.3)	—	.008
Totals	**3.6**										**49.2**		**1.37**
Chlorpyrifos	.96	9/2	95	9/3-5	10.6	(1.3)	1	1.4	13.1	6.0	(.8)	.08	.08
	.96	9/8	95										
	.96	9/15	95	[5]9/17-18	13.1	(2.1)	2	4.5	6.8	5.9	(1.2)	.06	.04
	—	—	—	[6]1/14			[7]118	—	N.D.< .1	—	—	—	—
Totals	**2.88**										**2.0**		**.07**
Sulprofos	1.68	9/2	95	9/3-5	10.6	(1.3)	1	N.D.	3.3	1.8	(.24)	.01	.01
	1.44	9/8	95										
	1.44	9/15	95	[5]9/17-18	13.1	(2.1)	2	.6	1.0	.9	(.18)	.006	.004
	1.44	9/23	95	[6]1/14	62	(18)	[7]110	—	N.D.< .02	—	—	—	—
Totals	**6.0**										**.42**		**.007**
Endosulfan	.82	9/23	95	[6]1/14	62	(18)	[7]110	.2	.7	.4	(.7)	.08	.08

[1]Mean concentration equals amount of pesticide in runoff divided by volume of runoff water. N.D. = not detectable.
[2]DCPA banded application; incorporated in top of beds at planting time.
[3]Runoff values in parentheses were estimated.
[4]Field weeded by hand crew 6/1/81, causing disturbance of banded DCPA.
[5]Last irrigation of cotton before harvest.
[6]1982.
[7]First furrow irrigation of cantaloups following cotton.

Table 14. — *Pesticides in irrigation runoff water from a 54-ha sugarbeet field irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 4, 1978-79)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1978	Percent canopy cover	Runoff dates in 1978	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Ethyl parathion	0.55	9/14	0	9/19-23	12.8	[2](2.8)	5	2.2	75	18.2	(5.6)	1.02	1.02
	.56	9/27	2	11/17-21	9.3	1.5	[3]51	.23	.74	.45	.07	.02	.007
	—	—	—	[4]1/5-7	8.2	2.9	100	.07	.14	.10	.03	—	.003
	—	—	—	[4]2/9-11	10.0	3.4	135	.02	.06	.03	.01	—	.001
	—	—	—	[4]2/25-27	8.9	3.0	152	—	N.D<.01		—	—	—
Totals	**1.11**										**5.71**		**.31**
Methyl parathion	.28	9/14	0	9/19-23	12.8	(2.8)	5	.8	24	6.1	(1.7)	.61	.61
	.28	9/27	2	11/17-21	9.3	1.5	[3]51	.03	.25	.08	.01	.005	.002
	—	—	—	[4]1/5-7	8.2	2.9	100	—	[5]N.D.< .01	—	—	—	—
Totals	**.56**										**1.71**		**.31**
Methomyl	.84	9/27	2										
	.84	10/5	3										
	.90	10/12	5										
	.91	10/23	10	11/17-21	9.3	1.5	[3]25	.8	73	21	3.21	.09	.09
	—	—	—	[4]1/5-7	8.2	2.9	74	8.3	32	16.3	4.74	—	.14
	—	—	—	[4]2/9-11	10.0	3.4	109	1.0	4	1.9	.66	—	.02
	—	—	—	[4]2/25-27	8.9	3.0	126	.6	.6	.6	.17	—	.005
Totals	**3.49**										**8.78**		**.25**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.
[2]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.
[3]Rainfall, 1.45 cm 10/21/78 and 0.61 cm 10/24/78.
[4]1979.
[5]Not detectable in all subsequent irrigations.

Table 15. — *Pesticides in irrigation runoff water from a 54-ha sugarbeet irrigated with a furrow irrigation system in Imperial Valley, Calif. during the 1979-80 crop year (field 4)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1979	Percent canopy cover	Runoff dates in 1979	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Ethyl parathion	0.53	9/9	1	9/14-19	11.6	5.0	5	2.2	11.5	6.6	3.32	0.63	0.63
	[2].53	9/16,20	3										
	.48	9/22	5										
	.53	9/30	7	10/7-9	9.6	2.4	7	.2	18	13.1	3.1	.20	0.15
	—	—	—	10/28-30	8.6	.91	28	.2	3	1.1	.10	—	.005
	—	—	—	[3]12/18-19	8.9	2.7	81	—	[4]N.D.< .01	—	—	—	—
Totals	**2.07**										**6.52**		**.31**
Methyl parathion	.26	9/9	1	9/14-19	11.6	5.0	5	.2	3.3	.9	.43	.14	.14
	[2].26	9/16,20	3	—									
	.24	9/22	5	—									
	.26	9/30	7	10/7-9	9.6	2.4	7	.3	8.5	5.1	1.2	.16	.12
	—	—	—	10/28-30	8.6	.9	28	.1	1.7	.4	.04	—	.004
	—	—	—	[3]12/18-19	8.9	2.7	81	—	[4]N.D.< .01	—	—	—	—
Totals	**1.02**										**1.67**		**.16**
Methomyl	[2].85	9/16,20	3	9/14-19	11.6	5.0	0	.3	6.9	3.6	1.83	—	—
	.86	9/22	5	—									
	.85	9/30	7	10/7-9	9.6	2.4	7	20	107	26	6.20	.24	.24
	.67	10/10	10	—									
	.78	10/26	15	10/28-30	8.6	.9	2	1	118	17	1.5	.10	.04
	—	—	—	[3]12/18-19	8.9	2.7	55	N.D.	8.3	1.1	.31	—	.008
	—	—	—	[5]1/29-30	10.9	[6](2.5)	95	N.D.	22	4.5	(1.1)	—	.03
	—	—	—	[5]3/10-11	10	2.3	134	N.D.	5.1	3.4	.8	—	.02
	—	—	—	[5]3/27-28	5.2	2.4	152	N.D.	[7]2.4	—	—	—	—
	—	—	—	[5]4/9-10	9.9	1.2	167	—	N.D.< .5	—	—	—	—
Totals	**4.01**										**11.74**		**.29**
Diazinon	.56	10/10	10										
	.56	10/26	15	10/28-30	8.6	.9	2	1.5	22	8.2	.75	.07	.07
	—	—	—	[3]12/18-19	8.9	2.7	55	—	[4]N.D.< .03	—	—	—	—
Totals	**1.12**										**.75**		**.07**
EPTC	[8]2.80	10/7	10	10/7-9	9.6	2.4	0	33	1408	850	202	7.2	7.2
	—	—	—	10/28-30	8.6	0.9	21	.8	11	3.5	.32	—	.01
	—	—	—	[3]12/18-19	8.9	2.7	74	—	N.D.< 0.5	—	—	—	—
Totals	**2.80**										**202**		**7.2**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.

[2]Applied to south half of field of 9/16 after runoff ceased; applied to north half of field on 9/20 after irrigation.

[3]Also irrigated 11/23/79, but no runoff samples were obtained.

[4]Not detectable in all subsequent runoff events; last irrigation 4/9-10/80, and sugarbeets harvested 5/80.

[5]1980.

[6]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.

[7]Methomyl detected in 1 sample only.

[8]EPTC applied in irrigation water at approximately 2 p/m.

Table 16. — *Pesticides in irrigation runoff water from a 54-ha alfalfa field irrigated with a border irrigation system in Imperial Valley, Calif. (field 4, 1981)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
EPTC	[2]2.2	5/20-22	60	5/20-22	11.4	0.7	0	345	1500	826	58	2.6	2.6
	[2]2.2	6/19-21	60	6/19-21	13.8	[3](2.0)	0	767	1630	1250	(250)	11.4	5.7
	—	—	—	6/29-7/1	11.2	(1.8)	10	3.6	3.6	3.6	(.6)	—	.01
	[2]2.2	9/3-5	60	9/3-5	10.5	(1.8)	0	169	1030	617	(111)	5.0	1.7
	—	—	—	[4]9/14-17	5.6	3.0	11	No samples taken			—	—	—
	—	—	—	9/27-29	13.3	(2.0)	25	1.0	1.0	1.0	(.2)	—	.003
	—	—	—	10/17-20	10.1	.6	44	—	N.D.< .5	—	—	—	—
	—	—	—	11/5-7	9.0	(1.6)	63	—	N.D.< .5	—	—	—	—
Totals	**6.6**										**420**		**6.4**
Methomyl	.62	8/6	95	[4]8/8-10		No samples taken		—	—	—	—	—	—
	.64	8/17	95	8/22-24	10.4	2.0	5	9.5	25	17	3.4	.53	.27
	—	—	—	9/3-4	10.5	(1.8)	17	N.D.	4	3	(.6)	—	.05
	—	—	—	[4]9/14-17	5.6	3.0	11	No samples taken			—	—	—
	.67	9/17	95	9/27-29	13.3	(2.0)	10	5.5	5.5	5.5	(1.1)	.16	.06
	—	—	—	10/17-20	10.1	.6	30	1.9	5.8	3.3	.2	—	.01
	—	—	—	11/5-7	9.0	(1.5)	49	—	N.D.< .6	—	—	—	—
Totals	**1.93**										**5.3**		**.27**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.
[2]EPTC (Eptam) applied in irrigation water at approximately 2 p/m.
[3]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.
[4]Not notified of irrigation, no samples taken.

Table 17. — *Pesticides in irrigation runoff water from a 60-ha sugarbeet field irrigated with a furrow irrigation system in Imperial Valley, Calif. during the 1979-80 crop year (field 5)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Ethyl parathion	.47	8/31	0	8/25-9/2				Sprinkler irrigated, no runoff					
	.48	9/5	1										
	.53	9/12	2										
	.50	9/18	3										
	.53	9/21	5	9/22-24	11.7	3.3	1	4.5	54	26.1	8.5	0.42	0.34
Methyl parathion	.24	8/31	0	8/25-9/2				Sprinkler irrigated, no runoff					
	.24	9/5	1										
	.26	9/12	2										
	.25	9/18	3										
	.26	9/21	5	9/22-24	11.7	3.3	1	1.5	27	6.4	2.1	.21	.17
Methomyl	.56	9/5	1										
	.85	9/12	2										
	.90	9/18	3										
	.85	9/21	5	9/22-24	11.7	3.3	1	3.8	91	38	12.4	.40	.40
	.85	10/1	7										
	1.12	10/9	10	10/12-14	8.4	1.6	3	2.5	223	21	3.4	.17	.07
	.69	10/18	15	11/7-9	13.3	2.4	20	2	163	15.7	3.7	.54	.06
	—	—	—	12/18-21	11.6	1.0	61	8	10	9	.9	—	.02
	—	—	—	[2]3/6-10	10.2	2.2	140	—	[3]N.D.< .3	—	—	—	—
Totals	**5.82**										**20.4**		**.35**
Diazinon	.48	10/18	15	11/7-9	13.3	2.4	20	.2	7	.72	.17	.04	.04
	—	—	—	12/18-21	11.6	1.0	61	.1	1.5	.2	.02	—	.004
	—	—	—	[2]3/6-10	10.2	2.2	140	—	[3]N.D.< .03	—	—	—	—
Totals	**.48**										**.19**		**.04**
Cycloate	[4]2.9	8/25-29	0	9/22-24	11.7	3.3	24	.5	6.2	2.5	.9	.03	.03
	—	—	—	10/12-14	8.4	1.6	44	—	[3]N.D.< .06	—	—	—	—
Totals	**2.9**										**.9**		**.03**
Malathion	1.96	[2]3/23	98	[2]4/3-5	9.0	2.7	11	4.7	10	6.2	1.7	.09	.09
	—	—	—	[2]4/14-17	9.4	2.7	22	N.D.	.4	.4	.1	—	.005
Totals	**1.96**										**1.8**		**.09**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.
[2]1980.
[3]Not detectable in all subsequent runoff events; last irrigation 5/20/80, and sugarbeets harvested 6/80.
[4]Cycloate (Ro-Neet), premergent herbicide applied by sprinkler irrigation with no runoff.

Table 18. — *Pesticides in irrigation runoff water from a 53-ha alfalfa field irrigated with a border irrigation system in Imperial Valley, Calif. (field 6, 1978, 1979, 1980)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date	Percent canopy cover	Runoff dates	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
						1978							
Mevinphos	0.14	3/12	95	3/14-16	10	3.1	2	0.3	26	1.26	0.39	0.274	0.274
						1979							
Malathion	1.38	2/2	95	2/12-13	8.9	1.0	10	5.9	16.4	11.5	1.12	.08	.08
	—	—	—	2/28-3/1	13.7	2.1	26	.4	1.5	.77	.15	—	.01
	1.70	3/12	95	3/29-30	17.6	1.4	[2]17	3.3	11.5	6.9	.97	.06	.03
	1.38	4/6	85	4/10-11	7.2	[3](1.0)	4	10.2	21.4	16.0	(1.6)	.12	.04
	—	—	—	4/26-28	18.6	1.6	20	.1	3.0	.53	.09	—	.002
	—	—	—	5/8-11	14.2	1.3	32	—	N.D.< .02	—	—	—	—
	—	—	—	5/24-26	17.2	.5	48	—	N.D.< .02	—	—	—	—
Totals	**4.46**										**3.93**		**.09**
						1980							
Malathion	1.70	2/11	95	3/10-12	7.6	.8	29	—	N.D.< .2	—	—	—	—
Ethyl parathion	.28	8/17	95	8/31-9/3	14.9	.8	14	.9	3.0	2.3	.18	.06	.06
Methyl parathion	.14	8/17	95	8/31-9/3	14.9	.8	14	N.D.	.3	.3	.02	.01	.01
Methomyl	.34	8/17	95										
	.45	8/26	95	8/31-9/3	14.9	.8	5	2.4	30	12.5	1.0	.13	.13

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.

[2]Rainfall, 1.4 cm over a 5-day period between malathion application and irrigation on 3/29-30/79.

[3]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.

Table 19. — *Pesticides in irrigation runoff water from a 53-ha cantaloup field irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 6, 1981)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1981	Percent canopy cover	Runoff dates in 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
Diazinon	[2]0.80	8/8	0	8/10-16	30.8	4.5	2	0.2	0.9	0.5	0.22	0.03	0.03
	.41	8/19	15										
	.41	8/20	16										
	.62	8/24	20	8/29-31	8.3	1.4	5	7.3	10.1	8.6	1.2	.08	.05
	.45	9/3	30	9/14-18	14.6	3.6	11	.15	.15	.15	[3].05	.01	.002
	—	—	—	9/26-30	9.7	4.6	23	—	N.D.< .03	—	—	—	—
Totals	**2.69**										**1.47**		**.05**
Endosulfan	1.19	9/22	40	9/26-30	9.7	4.6	4	4.2	73	36	16.7	1.4	1.4
	1.19	9/28	50										
	1.19	10/3	55	10/5-8	7.5	3.4	2	33	99	51	17.3	.73	.48
	1.19	10/8	60										
	1.19	10/15	70	10/19-21	5.8	0.4	4	47	104	71	2.7	.11	.05
Totals	**5.95**										**36.7**		**.62**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.

[2]Diazinon applied as granules in a 2-inch band on top of seed bed at planting time.

[3]Diazinon runoff based on 1 sample only.

Table 20. — *Pesticides in irrigation runoff water from a 58-ha alfalfa field irrigated with a border irrigation system in Imperial Valley, Calif. (field 7, 1980, 1981)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date in 1980 or 1981	Percent canopy cover	Runoff dates in 1980 or 1981	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
EPTC	[2]2.24	3/25-27	50	3/25-27	13.8	2.7	0	662	1575	1080	292	13	13
	—	—	—	4/11-13	10.4	2.4	13	2	10	.8	1.9	—	.08
	—	—	—	5/7-8	17.2	1.4	38	—	N.D.< .5	—	—	—	—
	—	—	—	5/21-22	12.7	2.3	51	N.D.	4	2.5	.6	—	.03
	[2]2.24	8/4-5	50	[3]8/4-6	11.9	1.6	0	168	847	450	72	3.2	1.6
	—	—	—	8/13-14	9.4	2.4	9	1	3	2	.5	—	.01
	—	—	—	8/20-22	9.7	2.7	15	N.D.	1	.5	.1	—	.003
	—	—	—	9/5-7	12.5	2.2	25	—	[4]N.D.< .5	—	—	—	—
	[2]2.20	[5]3/10-12	50	[5]3/10-12	10.6	1.4	0	118	1530	993	139	6.3	2.1
	—	—	—	[5]3/27-28	5.9	[6](1.5)	17	N.D.	[7]82	—	—	—	—
	[2]2.7	[5]4/16-18	50	[5]4/17-19	17.6	2.1	0	590	1120	830	174	6.4	1.85
	—	—	—	[5]4/26-27	No samples taken			—	—	—	—	—	—
	[2]2.2	[5]5/10-13	50	[5]5/11-13	18.1	2.0	0	63	1140	780	156	7.1	1.35
	—	—	—	[5]5/24-25	12.0	(2.0)	11	4	5	4.2	(.8)	—	.007
	—	—	—	[5]6/3-4	11.7	1.8	21	—	N.D.< .5	—	—	—	—
	[2]2.2	[5]6/17-19	50	[5]6/18-20	13.4	(2.0)	0	182	1000	485	(97)	4.4	.70
	—	—	—	[5]6/26-28	11.4	(1.8)	9	1	3	2.1	(.4)	—	0.003
	—	—	—	[5]7/5-7	10.0	(2.0)	18	.5	.7	.6	(.1)	—	< .001
	—	—	—	[5]7/19-21	12.2	(2.1)	30	—	[8]N.D.< .5	—	—	—	—
Totals	**13.78**										**934**		**6.78**
Methomyl	.55	8/15	90	8/20-22	9.7	2.7	5	2	39	22	5.8	1.1	1.1
	.77	8/22	90	9/5-7	12.5	2.2	13	2	4	2.8	.6	.08	.05
	.75	9/12	90	9/14-15	9.4	(2.0)	3	33	91	54	(10.6)	1.4	.52
	.77	9/19	90	9/26-28	10.0	1.9	7	19	41	31	5.9	.77	.21
	—	—	—	10/15-18	10.1	(1.1)	26	2	3	2.3	(.3)	—	.01
	.74	10/18	90	11/3-5	9.9	2.6	15	7	64	25	6.4	.86	.19
	.74	11/6	90	11/26-29	9.7	(1.9)	22	19	22	21	(4.0)	.54	.10
	.38	[5]2/1	90	2/2-3	11.3	(2.0)	1	21	21	21	[9](4.1)	1.1	0.09
	—	—	—	[5]3/10-12	10.6	1.4	37	—	[10]N.D.< .6	—	—	—	—
	.84	[5]8/2	90	[5]10/7-10	20.4	2.0	66	1.2	27	9.5	1.9	.23	.04
Totals	**5.54**										**39.6**		**.71**

[1]Mean concentration equals amount of pesticide divided by volume of runoff water. N.D. = not detectable.
[2]EPTC (Eptam) applied in irrigation water at approximately 2 p/m.
[3]Irrigated 5 times between 5/22/80 and 8/4/80 with no runoff samples taken or N.D. levels observed.
[4]Also not detectable in runoff from 6 subsequent irrigations between 9/15/80 and 2/2/81.
[5]1981.
[6]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.
[7]EPTC detected only in 1 sample at start of runoff when flow volume was very low.
[8]EPTC also not detectable in runoff from all subsequent irrigations.
[9]Methomyl in runoff based on 1 sample only.
[10]Methomyl not detectable in runoff from 11 subsequent irrigations until again applied on 8/2/81.

Table 21. — *Pesticides in irrigation runoff water from lettuce, onion, and cantaloup fields irrigated with furrow irrigation systems in Imperial Valley, Calif.*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date	Percent canopy cover	Runoff dates	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
					Lettuce, field 8, 28 ha, 1979								
Diazinon	.45	11/2/78	5										
	.32	11/14/78	8	1/31-2/1	3.3	.53	[2]78	N.D.	3.1	0.45	0.024	—	0.003
	—	—	—	2/16-17	4.4	1.2	94	.04	.3	.17	.02	—	.003
	—	—	—	2/24-25	4.4	.7	102	.06	1.2	.86	.06	—	.008
Totals	**.77**										**.104**		**.014**
Malathion	1.6	1/11/79	30	1/31-2/1	3.3	.53	[3]20	.04	4.5	.24	.013	.001	.001
	1.6	2/2/79	50	2/16-17	4.4	1.2	[4]14	5.5	36	13.3	1.60	.10	.05
	—	—	—	2/24-25	4.4	.7	22	.5	4.2	.9	.06	—	.002
Totals	**3.2**										**1.67**		**.052**
Ethylan	1.6	1/11/79	30	1/31-2/1	3.3	.53	[3]20	N.D.	6.8	.37	.02	.001	.001
	1.6	2/2/79	50	2/16-17	4.4	1.2	[4]14	N.D.	8.0	2.0	.23	.014	.007
	—	—	—	2/24-25	4.4	.7	22	N.D.	1.7	.14	.01	—	< .001
Totals	**3.2**										**.26**		**.008**
					Lettuce, field 9, 56 ha, 1978								
Methyl parathion	.53	10/27	2	[5]12/9	3.2	1.1	[6]43	.03	.23	.08	.009	.002	.002
	.53	11/1	2	[7]12/11	2.8	.8	[6]40	N.D.	.26	.09	.007	.001	.001
					Onions, field 3, 14 ha, 1979								
DCPA[8]	5.6	2/12	<5	2/21-23	15.9	2.9	9	1.2	29	8.3	2.4	.04	.04
					Cantaloup, field 3, 28 ha, 1982								
Trifluralin	[13].85	3/22/82	10	3/26-4/2	25.1	6.5	4	.19	8	1.25	.81	.10	.10
					Onions, field 5, 60 ha, 1981-82								
DCPA[9]	7.8	11/9/1	0	12/22-23	[10]—	[11](.01)	45	14	21	20	(.02)	—	< .001
	—	—	—	1/26-30	[12]10.2	(2.3)	78	25	36	30	(6.9)	—	.09

[1]Mean concentration equals amount of pesticide divided by volume of runoff water.
[2]Third irrigation since last diazinon application on 11/14/78.
[3]Rainfall, 2.23 cm in 5 events between application 1/11/79 and irrigation on 1/31/79.
[4]Rainfall, 0.2 cm in 1 event between application 2/2/79 and irrigation on 2/16/79.
[5]First irrigation after methyl parathion application to middle one-third of field.
[6]Rainfall, 1.65 cm between methyl parathion applications and first irrigations.
[7]First irrigation after methyl parathion application to north one-third of field.
[8]DCPA herbicide applied to 2-mo-old onions by spraying in a 14- to 16-inch band across top of beds.
[9]DCPA applied by spraying 14-inch band on top of onion beds at planting time.
[10]Second sprinkler irrigation after planting with very low runoff; no runoff from first irrigation.
[11]Runoff values in parentheses were estimated from partial hydrograph or limited staff-gage readings.
[12]First furrow irrigation after planting.
[13]Trifuluralin applied with a Lilliston rig in furrows and on shoulders of the beds.

Table 22. — *Pesticides in irrigation runoff water from small fields of lettuce and cotton irrigated with a furrow irrigation system in Imperial Valley, Calif. (field 10)*

Pesticide application				Irrigation runoff				Pesticides in runoff					
								Concentration[1]					
Chemical	Rate	Date	Percent canopy cover	Runoff dates	Water applied L/ha × 10^5	Runoff volume L/ha × 10^5	Days since last pesticide application	Minimum	Maximum	Mean	Amount	Percent of applied since last irrigation	Percent of total applied
	Kg/ha				*Cm*	*Cm*		*P/b*	*P/b*	*P/b*	*G/ha*		
					Lettuce, 0.74 ha, 1979								
Methomyl	0.85	10/31/78	1										
	.91	11/18/78	5										
	1.13	11/28/78	10	1/11-12	[2]12	7.9	44	0.7	9.0	4.5	3.6	[3]0.32	0.13
	—	—	—		[2]22	14.3	44	.5	18.4	7.8	11.2	[3].99	.39
	.84	1/2/79	60										
	[4]—	—	—	3/12-13	7.2	3.5	59	.4	.8	.6	.2	.03	.007
					Cotton, 2.4 ha, 1979								
Permethrin	.11	7/7	60										
	.11	7/15	70	7/17-18	14.9	2.2	2	—	N.D.< .7	—	—	—	—
					Cotton, 2.4 ha, 1981								
Permethrin	.19	7/12	70	7/15-16	15.4	[5](2.3)	3	—	N.D.< .7	—	—	—	—
	.19	7/17	75										
	.19	7/24	85	7/27-28	15.4	(2.3)	3	—	N.D.< .7	—	—	—	—
	.20	8/1	90	8/6-7	15.4	(2.3)	5	—	N.D.< .7	—	—	—	—
	.20	8/7	95										
	.20	8/15	95	8/20-21	15.4	(2.3)	5	—	N.D.< .7	—	—	—	—
	—	—	—	9/3-4	15.4	(2.3)	19	—	N.D.< .7	—	—	—	—
Totals	**1.17**										**N.D.**		—

[1]Mean concentration calculated from the amount of pesticide in runoff divided by the runoff volume. N.D. = not detectable.
[2]Approximately 12 cm water applied to one-half of field and 22 cm to other half; runoff measured and sampled from each half of field separately.
[3]Sprinkler irrigated on 1/4-5/79; 0.61 cm rain fell on 1/6-7 with no runoff occurring between methomyl application on 11/28/78 and irrigation on 1/11-14/79.
[4]Residual methomyl runoff from first irrigation of cotton crop following the application of 3.73 kg/ha methomyl to lettuce.
[5]Runoff values in parentheses were estimated.

Table 23. — *Pesticides runoff summary—total seasonal losses in irrigation runoff water for fields 1-8*[1]

Pesticide	Field No.	Year	Crop	Total amount applied	Pesticides in runoff	
					Total amount	Percent of Total applied
				Kg/ha	*Kg/ha*	
HERBICIDES						
Cycloate	5	1979	Sugarbeets	2.9	0.9	0.03
DCPA	1	1980	Cotton	7.6	92.6	1.22
	1	1981	--do--	3.4	47.7	1.40
	3	1981	--do--	3.6	49.2	1.37
Dinitramine	1	1979	--do--	1.3	17.3	1.32
EPTC[2]	4	1979	Sugarbeets	2.8	202	7.2
	4	1981	Alfalfa	6.6	420	6.4
	7	1980/81	--do--	13.8	934	6.8
Prometryn	1	1979	Cotton	3.1	157	5.0
	1	1980	--do--	1.6	23.5	1.5
	1	1981	--do--	1.6	27.2	1.7
	2	1980	--do--	1.3	12.4	.95
Trifluralin	1	1981	--do--	1.1	3.21	.29
	2	1980	--do--	.96	1.38	.14
INSECTICIDES						
Organophosphates						
Azinphosmethyl	1	1979	Cotton	.52	N.D.	N.D.
Chlorpyrifos	1	1979	--do--	1.68	.29	.02
	1	1980	--do--	.70	.61	.09
	1	1981	--do--	2.44	5.96	[3].24
	2	1980	--do--	.96	.23	.02
	3	1981	--do--	2.88	2.00	.07
Diazinon	4	1979	Sugarbeets	1.12	.75	.07
	5	1979	--do--	.48	.19	.04
	6	1981	Melons	2.69	1.47	.05
Malathion	1	1981	Cotton	1.31	N.D.	N.D.
	3	1978	--do--	1.12	.004	.0003
	5	1980	Sugarbeets	1.96	1.8	.09
	6	1979	Alfalfa	4.46	3.93	.09
	6	1980	--do--	1.70	N.D.	N.D.
	8	1979	Lettuce	3.20	1.67	.05
Methidathion	2	1980	Cotton	1.12	2.3	.21
	3	1978	--do--	1.12	1.76	.16
	3	1979	--do--	1.02	20.5	[4]2.0
Mevinphos	6	1978	Alfalfa	.14	.39	.27
Ethyl parathion	2	1981	Lettuce	.83	.18	.02
	3	1980	--do--	4.20	18.4	.44
	4	1978	Sugarbeets	1.11	5.71	.51
	4	1979	--do--	2.07	6.52	.31
	5	1979	--do--	2.51	8.50	.34
	6	1980	Alfalfa	.28	.18	.06

Table 23. — *Pesticides runoff summary—total seasonal losses in irrigation runoff water for fields 1-8*[1] *(continued)*

Pesticide	Field No.	Year	Crop	Total amount applied	Pesticides in runoff	
					Total amount	Percent of Total applied
				Kg/ha	*Kg/ha*	
Methyl parathion	2	1981	Lettuce	.42	.013	.003
	3	1980	--do--	2.1	6.70	.32
	4	1978	Sugarbeets	.56	1.71	.31
	4	1979	--do--	1.02	1.67	.16
	5	1979	--do--	1.25	2.10	.17
	6	1980	Alfalfa	.14	.02	.01
Sulprofos	3	1978	Cotton	4.55	.02	.001
	3	1981	--do--	6.0	.42	.007
Carbamates						
Methomyl	1	1980	Cotton	.4	6.9	1.73
	2	1981	Lettuce	3.41	16.3	.48
	3	1980	--do--	3.16	21.1	.67
	4	1978	Sugarbeets	3.49	8.78	.25
	4	1979	--do--	4.01	11.7	.29
	4	1981	Alfalfa	1.93	5.3	.27
	5	1979	Sugarbeets	5.82	20.4	.35
	6	1980	Alfalfa	.79	1.00	.13
	7	1980/81	--do--	5.54	39.6	.71
Organochlorines						
Endosulfan	2	1981	Lettuce	1.66	3.18	.19
	6	1981	Melons	5.95	36.7	.62
Ethylan	8	1979	Lettuce	3.2	.26	.008
Pyrethroids						
Fenvalerate	1	1979	Cotton	.57	.58	[5].10
	1	1980	--do--	.27	.15	.05
	1	1981	--do--	.49	1.02	0.21
	2	1980	--do--	1.23	1.06	[6].09
	3	1979	--do--	.54	.50	[5].09
Permethrin	1	1979	Cotton	.71	1.12	[7].16
	1	1980	--do--	.51	N.D.	N.D.
	1	1981	--do--	1.22	.34	.028
	2	1980	--do--	.10	N.D.	N.D.
	3	1978	--do--	.51	N.D.	N.D.
	3	1979	--do--	.60	.54	.09

[1]See tables 5-21 for data on individual pesticide applications and irrigation runoff events.
[2]All EPTC applications were made in irrigation water at a concentration of about 2 ppm.
[3]69 percent of the total chlorpyrifos loss for the season occurred when chlorpyrifos was applied by airplane while irrigation was in progress.
[4]99 percent of the total methidathion loss occurred following an aerial application during irrigation.
[5]90 percent of the seasonal loss of fenvalerate occurred following an aerial application during irrigation.
[6]63 percent of the seasonal loss of fenvalerate occurred within 5 hr following an aerial application during irrigation.
[7]99 percent of the seasonal permethrin loss occurred following an aerial application during irrigation.
Note: N.D. = Not detectable.

The amounts of pesticides in the runoff water varied considerably depending upon the pesticide, its method of application, and the irrigation runoff volume or irrigation efficiency. The percentages of the applied pesticide lost in runoff water were generally very low with the exception of (a) EPTC applied directly in irrigation water; (b) insecticides applied by air while irrigation water was on the field; and (c) one herbicide, prometryn, applied at midseason as a directed spray to growing cotton. Each of these exceptions will be subsequenlty discussed.

Concentrations were highest in the first irrigation following pesticide application. The time elapsed between application and the first irrigation was inversely related to concentrations of pesticides in the runoff water. In general, higher runoff rates occurred from soil applied herbicides than from aerially applied insecticides, and the herbicides persisted longer than did the insecticides. This persistence may be related more to their incorporation in the soil than to their inherent persistence.

The amounts of individual herbicides lost in runoff depended upon the herbicide and its method of application. Four herbicides (prometryn, dinitramine, DCPA, and trifluralin) were applied to cotton, either before planting (preplant) as a band application in the top of the beds, or at midseason by spraying over the entire ground surface and mulching-in with a Lilliston rig. Seasonal losses of prometryn, DCPA, and dinitramine in runoff were 1 to 2 percent of the amounts applied with the exception of prometryn on field 1 in 1979. Trifluralin was lost in much smaller amounts than the other herbicides.

In 1979, 5 percent of the applied prometryn was lost in runoff water from field 1, mainly due to an exceedingly high loss in the first runoff event of July 24 to 26, 1979, 5 days after a midseason application of prometryn over the entire ground surface (table 5). A light rainfall of 0.86 cm fell in the intervening 5-day period, which probably resulted in movement of prometryn from the bed shoulders to the furrow and contributed to the high loss rate of 8 percent of the material applied prior to the irrigation. The midseason applications of herbicides usually resulted in higher concentrations and amounts of herbicides in runoff than preplant applications because of their closer proximity to the irrigation furrow.

Most of the herbicide losses occurred during the first irrigation after application. For example, with prometryn in field 1, 1979, 1980, 1981, and field 2, 1980, 57.5, 46.4, 70.4, and 75 percent, respectively, of the total losses occurred during the first irrigations following application (tables 5-8). The effectiveness of the first irrigations after application was even greater with insecticides that are sprayed on the foliage and the soil surface in contrast with the herbicides that are applied to the soil and mulched-in or incorporated to a shallow depth.

When prometryn and DCPA were applied together either before planting or at midseason to cotton, DCPA appeared in runoff water at a higher concentration because it was applied at a higher rate (tables 6 and 7); however, the percentages of the applied amounts found in runoff were comparable, that is, 1.7 percent for prometryn in 1980 and 1981 and 1.22 and 1.4 percent for DCPA in 1980 and 1981, respectively. DCPA is less soluble than prometryn (0.5 p/m compared with 48 p/m) and appeared to be more persistent as indicated by its presence in runoff water at significant concentrations throughout both growing seasons. In 1981, one preplant application of DCPA provided detectable levels of DCPA in runoff to the end of the growing season, 173 days after application (table 7).

When the two herbicides, prometryn and trifluralin, were applied together at midseason to cotton (table 8), prometryn was found in runoff water at a much higher concentration than trifluralin during the first three irrigations, but trifluralin persisted longer and was found in all subsequent irrigation runoff events until the end of the cotton-growing season. This persistence is probably related to its lower water solubility (0.3 p/m) and its greater adsorption on soil particles. Its lower concentration than prometryn in the earlier irrigations may be related to its tendency to volatilize rapidly or to decompose by photolysis in sunlight at the soil surface. The total amounts of trifluralin lost in runoff were always lower than for prometryn or the other soil applied cotton herbicides.

The amounts of insecticides in runoff water varied over a wide range depending upon the pesticide, the crop to which it was applied, and, apparently, the canopy coverage at the time of aerial application, The canopy coverage affects the amount of the chemical reaching the soil surface in the furrows subsequently exposed to irrigation water. The amount of insecticides in runoff appeared to be highly dependent upon the persistence of the insecticide at the soil surface.

All seasonal totals for insecticide runoff were below 1 percent of the amounts applied (with the exception of methomyl applied at a relatively low rate to a cotton crop in May 1980 (table 6) while the canopy coverage was only about 25 percent established). Of the organophosphate insecticides, chlorpyrifos, diazinon, and sulprofos were found in runoff water in extremely low amounts, generally equivalent to less than 0.1 percent of the amounts applied. Methidathion, ethyl parathion, methyl parathion, methomyl, and endosulfan usually appeared in runoff in

amounts between 0.16 and 0.67 percent of the amounts applied. Of the other insecticides, ethylan (Perthane) and the pyrethroids, fenvalerate and permethrin, were present in runoff water at extremely low rates, except on the rare occasions when they were applied while irrigation water was on the field.

With insecticides, a much higher percentage of the loss occurred during the first irrigation after application than with soil-applied herbicides, probably because the insecticides were present only on the soil surface and were not incorporated as were the herbicides.

It is interesting to compare runoff of two or more insecticides applied at the same time. Ethyl and methyl parathion were applied four times to a sugarbeet crop on field 4 during September 1979 with runoff measured in four subsequent irrigations (table 15). Ethyl parathion was applied at twice the rate of methyl parathion but appeared in the runoff water in amounts about four times that of methyl parathion. Of the 2.07 kg/ha of applied ethyl parathion, 6.52 g/ha or 0.31 percent appeared in the runoff water; of the 1.02 kg/ha applied methyl parathion, 1.67 g/ha or 0.16 percent appeared in the runoff water. Almost all the ethyl and methyl parathion in runoff occurred during the first irrigation after application, as only very low concentrations were observed in the second irrigation. Neither ethyl parathion nor methyl parathion was detected in the third irrigation after appication or in any subsequent irrigation during the growth of the crop.

Some of the observed relationships between water runoff hydrographs, pesticide concentrations, and pesticide flux rates under the various conditions of pesticide use and irrigation efficiency are shown in figures 1 to 6. In figures 1 and 2 are the water runoff hydrograph, the prometryn concentrations in runoff, the flux or rate of loss, and the accumulative percent loss of prometryn with time after initiation of runoff from field 1 for runoff event July 24 to 26, 1979 (table 5). This was the first runoff event after a midseason prometryn application, which resulted in loss of 8 percent of the applied prometryn. Concentrations were highest during the initial runoff period with a high of 1,400 parts per billion (p/b) in the first sample; concentrations decreased to less than 100 p/b within 5 hr as runoff volumes increased. This was somewhat atypical in that the inital prometryn concentration was much higher than observed in other runoff events, resulting in a higher than normal flux of prometryn before the peak waterflow was reached.

The concentrations of prometryn, the water runoff hydrograph, and the flux of prometryn at various times after the initiation of runoff on October 2 to 4, 1979, 75 days after the midseason application of prometryn, are shown in figure 3 (table 5). Prometryn concentrations were highest in the first runoff samples. Most of the prometryn runoff occurred during the first half of the irrigation cycle.

Figure 1. — Water runoff hydrograph and prometryn concentrations at various times after initiation of runoff from field 1 for runoff event July 24-26, 1979 (table 5). Prometryn was applied to cotton during midseason at 0.90 kg/ha by spraying over the entire ground surface and mulching-in with a Lilliston rig 5 days prior to the irrigation.

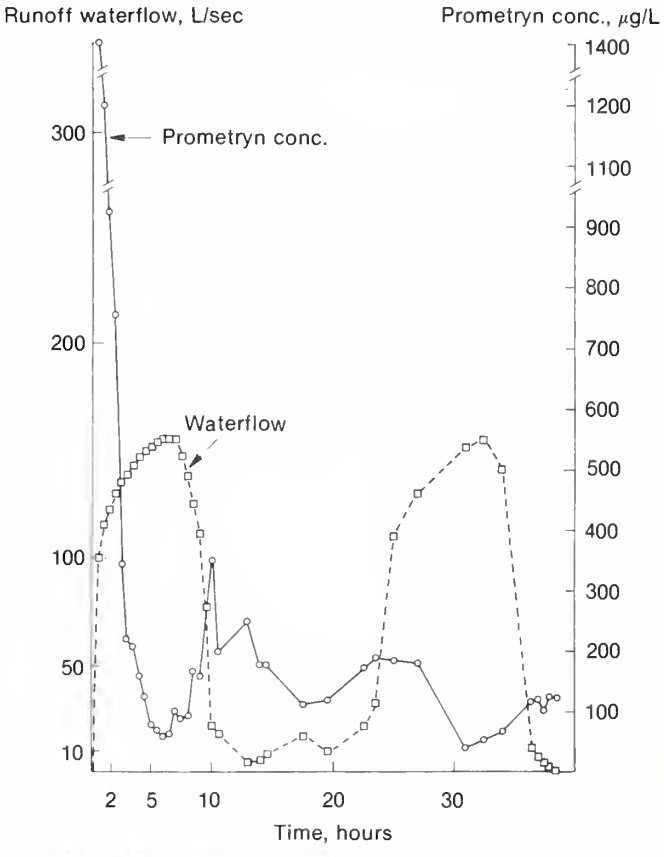


Figure 4 shows the concentrations and flux of cycloate and the water runoff hydrograph from field 5, 24 days after the preemergence herbicide had been applied by sprinkler irrigation prior to sugarbeet emergence (runoff of September 22-24, 1979, table 17). The field was irrigated in three individual irrigation "sets" with approximately one-third of the field being irrigated during each set and runoff almost stopping between sets. The concentration of cycloate generally followed an inverse relationship, and flux a direct relationship, with runoff volume.

Only very small amounts of either pryethroid, fenvalerate or permethrin, appeared in the runoff water except when they were applied while irrigations were in progress

(August 23, 1979, table 5). The increase in concentration following an aerial application with water on the field is illustrated in figure 5 where permethrin was applied at 0.2 kg/ha to cotton in field 1 while an irrigation was in progress. Prior to the application of permethrin, runoff water samples contained nondetectable amounts of permethrin; after application, concentrations immediately increased to a high of 71 p/b. Concentrations remained high for 1 to 2 hr following application, then decreased more slowly and returned to nondetectable levels after 8 to 10 hr of runoff. In this case, 98 percent of the total permethrin runoff loss from the cotton crop, which received five applications and a total of 0.71 kg/ha permethrin, occurred immediately following its application during the irrigation event on August 23, 1979.

Other insecticides showed similar large increases in concentration following aerial applications during irrigation.

Figure 2. — Water runoff hydrograph, flux, and accumulative percent loss of prometryn from field 1 for runoff event July 24-26, 1979, 5 days after a midseason application of 0.90 kg/ha prometryn.

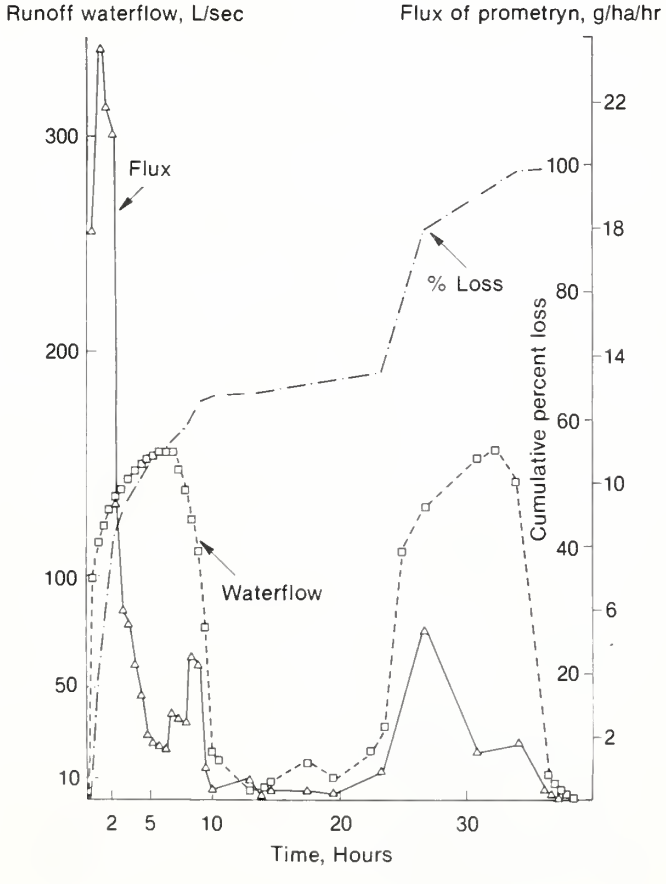
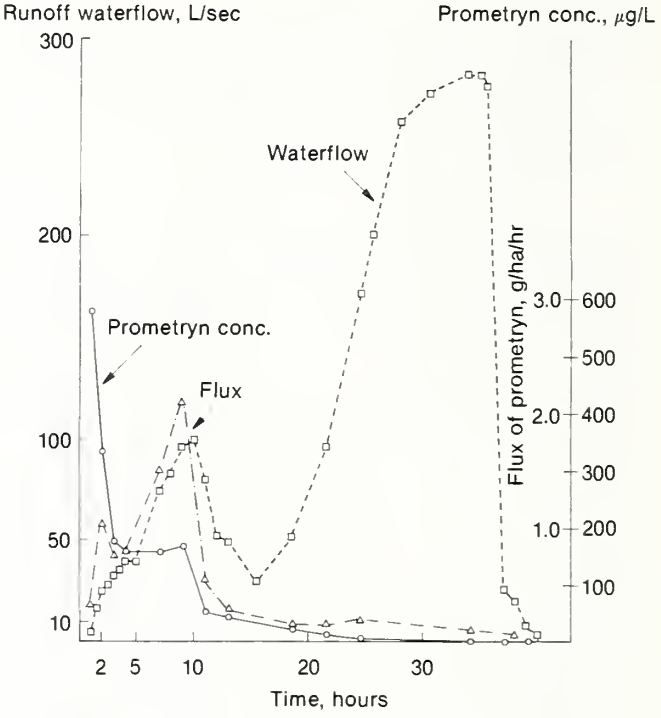


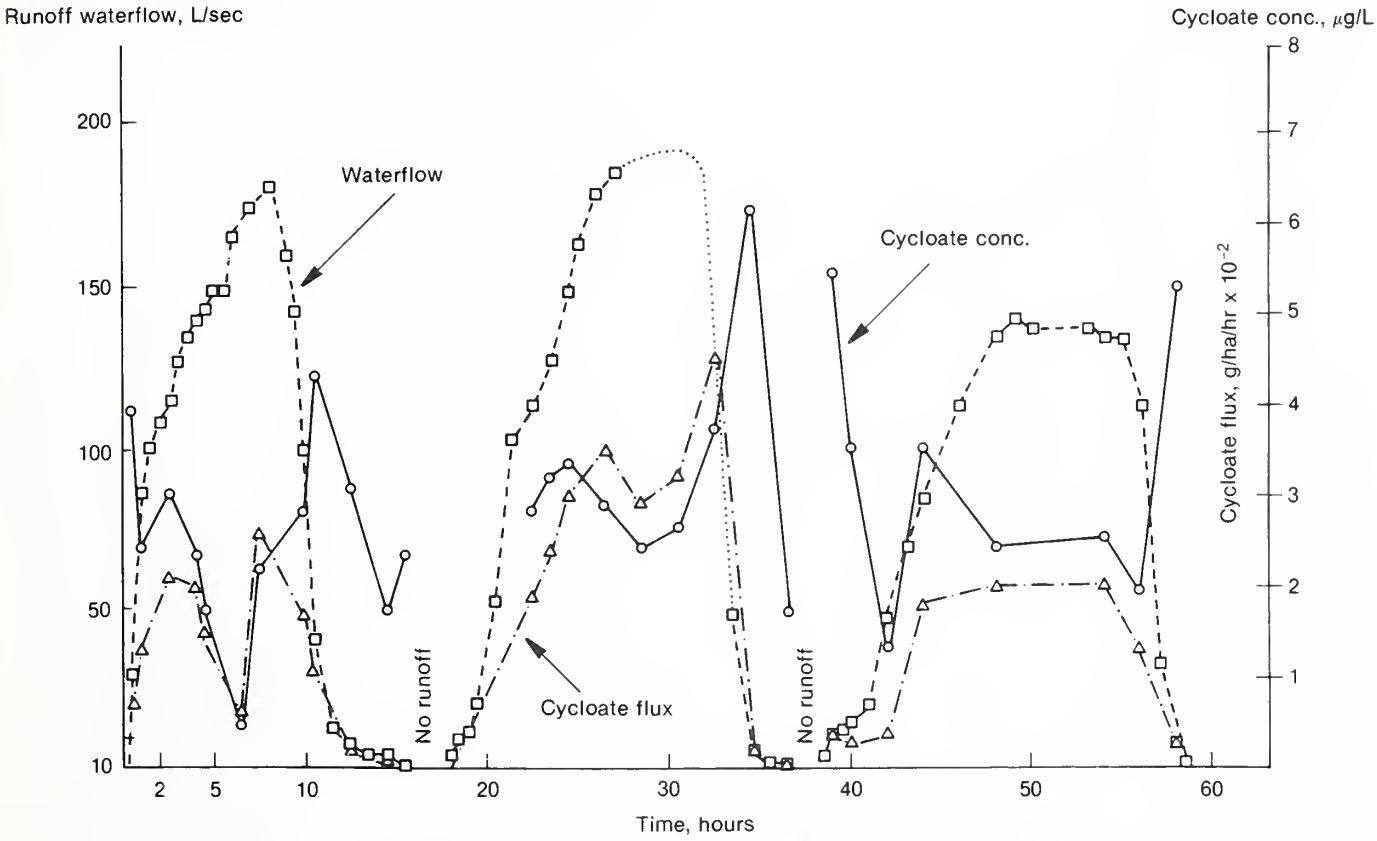
Figure 3. — Water runoff hydrograph, concentration, and flux of prometryn in runoff from field 1 on October 2-4, 1979, 75 days after the midseason application of prometryn to cotton (table 5).



For example, methidathion was applied at 0.54 kg/ha during an irrigation on July 29, 1979 (table 11), which resulted in an increase of methidathion concentration from approximately 1 to 473 µg/L immediately after its application. Concentrations decreased to about 10 µg/L within 3 hr. The application of insecticides while irrigation water is on the field is obviously something that should be avoided since it results in very high concentrations in runoff water from the direct application of the insecticide to the tailwater in the runoff ditch as well as to the water in furrows or borders. Since most of the aerial insecticide applications are made at night, these unusual occurrences may be the result of a lack of coordination between the pest control advisor and the farm foreman or owner.

Figure 6 shows the water runoff hydrograph for the October 7 to 9, 1979, irrigation on field 4 (table 15), 7 days after the last of three applications of 0.85 kg/ha methomyl, 0.53 kg/ha ethyl parathion, and 0.26 kg/ha methyl parathion. The flux rates of methomyl at various times after initiation of runoff are shown as well as the

Figure 4. — Water runoff hydrograph, concentration, and flux of cycloate in runoff from field 5 on September 22-24, 1979, 24 days after the preemergent herbicide had been applied by sprinkler irrigation prior to sugarbeet emergence (table 17).

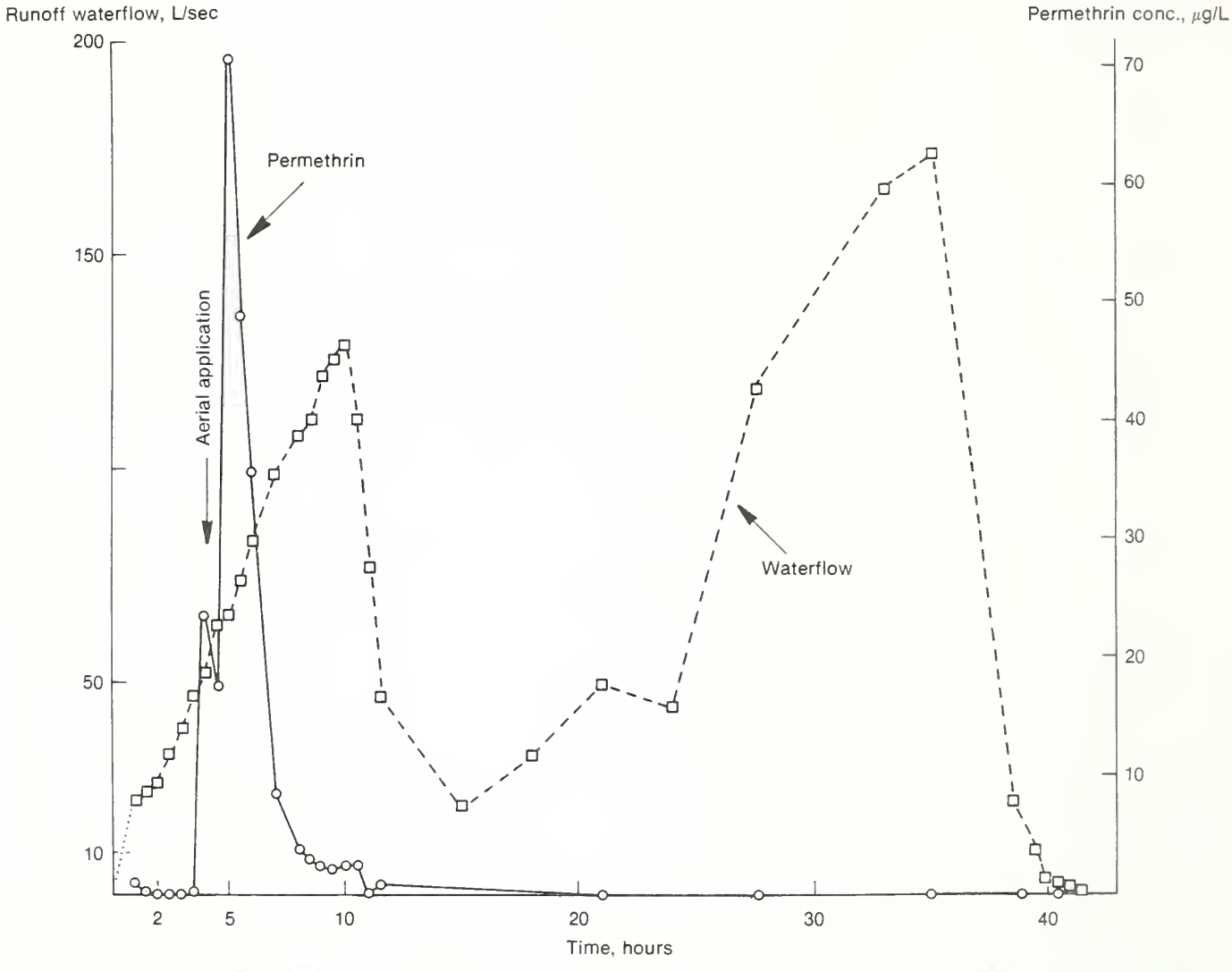


concentrations of the three insecticides. The typical pesticide concentration-water runoff hydrograph was observed with generally an inverse relationship between runoff volume and concentration occurring throughout most of the runoff period. Methomyl concentrations were higher than either ethyl or methyl parathion, but the total percentage applied found in runoff was similar for methomyl and ethyl parathion (table 15). The methomyl flux curve shows that the waterflow volume, within a particular event, is more important than pesticide concentration in controlling the amount of loss as the flux curve follows, generally, the waterflow curve of the hydrograph. The higher concentrations of pesticides occur at low waterflow volumes and thus contribute less than would be expected to the total pesticide runoff.

Figure 7 shows the water runoff hydrograph and diazinon concentrations in the runoff event of November 7 to 9, 1979, from sugarbeets in field 5 following the application of 0.48 kg/ha diazinon 20 days prior to irrigation (table 15). The concentration-hydrograph relationship again shows the usual high concentration of pesticides in the first water running off the field and the inverse relationship between runoff volume and pesticide concentration.

Relatively high losses of EPTC occurred when it was applied in irrigation water. EPTC in runoff water was measured following several applications to alfalfa and one application to sugarbeets at a concentration of approximately 2 p/m EPTC in the irrigation water. The tailwater runoff contained a high of 1,575 p/b EPTC with total amounts lost equivalent to between 2.6 and 13 percent of the applied EPTC on alfalfa and 7.2 percent of the applied EPTC on sugarbeets. Runoff of EPTC in subsequent irrigations was very low, indicating a low persistence of EPTC. For example, on sugarbeets the mean EPTC con-

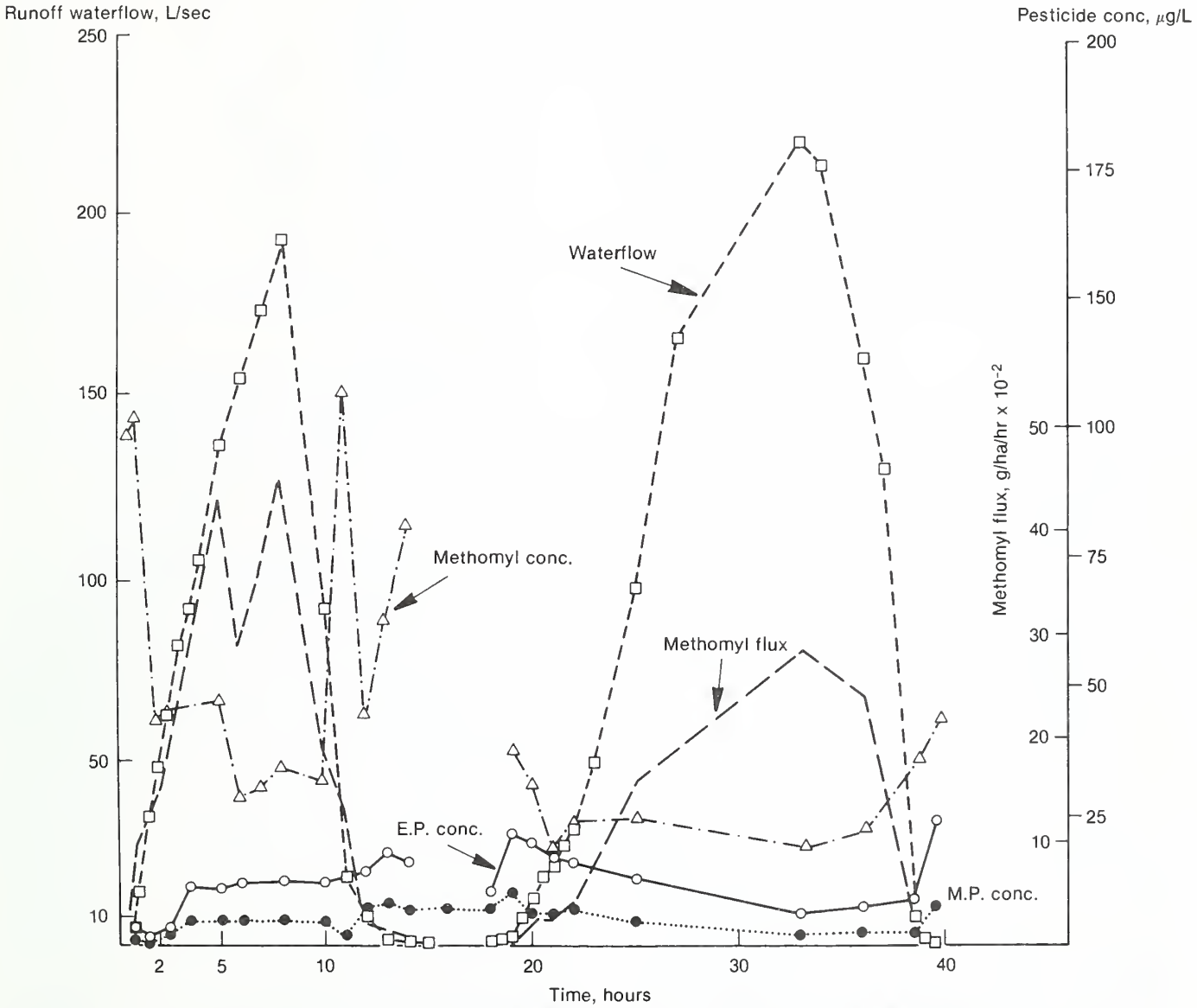
Figure 5 — Water runoff hydrograph and permethrin concentration in runoff water from field 1 before and after the aerial application of permethrin to cotton at 0.2 kg/ha while irrigation was in progress during runoff event of August 22-24, 1979 (table 5).



centration decreased from 850 p/b during the application irrigation to 3.5 p/b during the second irrigation 21 days later and was not detectable in the third irrigation. Similar results were observed with EPTC applications to alfalfa. This low persistence and low rate of runoff in subsequent irrigations is probably a reflection of the high volatilization rate of EPTC from the soil surface.

With the highly volatile herbicide EPTC, temperature and other factors related to evaporation potential appear to be important in controlling the concentrations and amounts lost in runoff water during the application irrigation (Cliath et al. *1980*). This was particularly noted in 1980 on field 7 (table 20) where much higher concentrations and total amounts of EPTC in runoff occurred during the March application (292 g/ha or 13 percent of the amount applied) than in August (72 g/ha or 3.2 percent of the amount applied). The difference is probably a reflection of temperature differences, with the lesser potential for loss through vaporization in March than in August as the

Figure 6. — Water runoff hydrograph; concentrations of methomyl, ethyl parathion (E.P.), and methyl parathion (M.P.); and flux of methomyl at various times after initiation of runoff from field 4 on October 7-9, 1979, 7 days after the last of three applications of the insecticides to sugarbeets at rates of 0.85, 0.53, and 0.26 kg/ha, respectively (table 15).

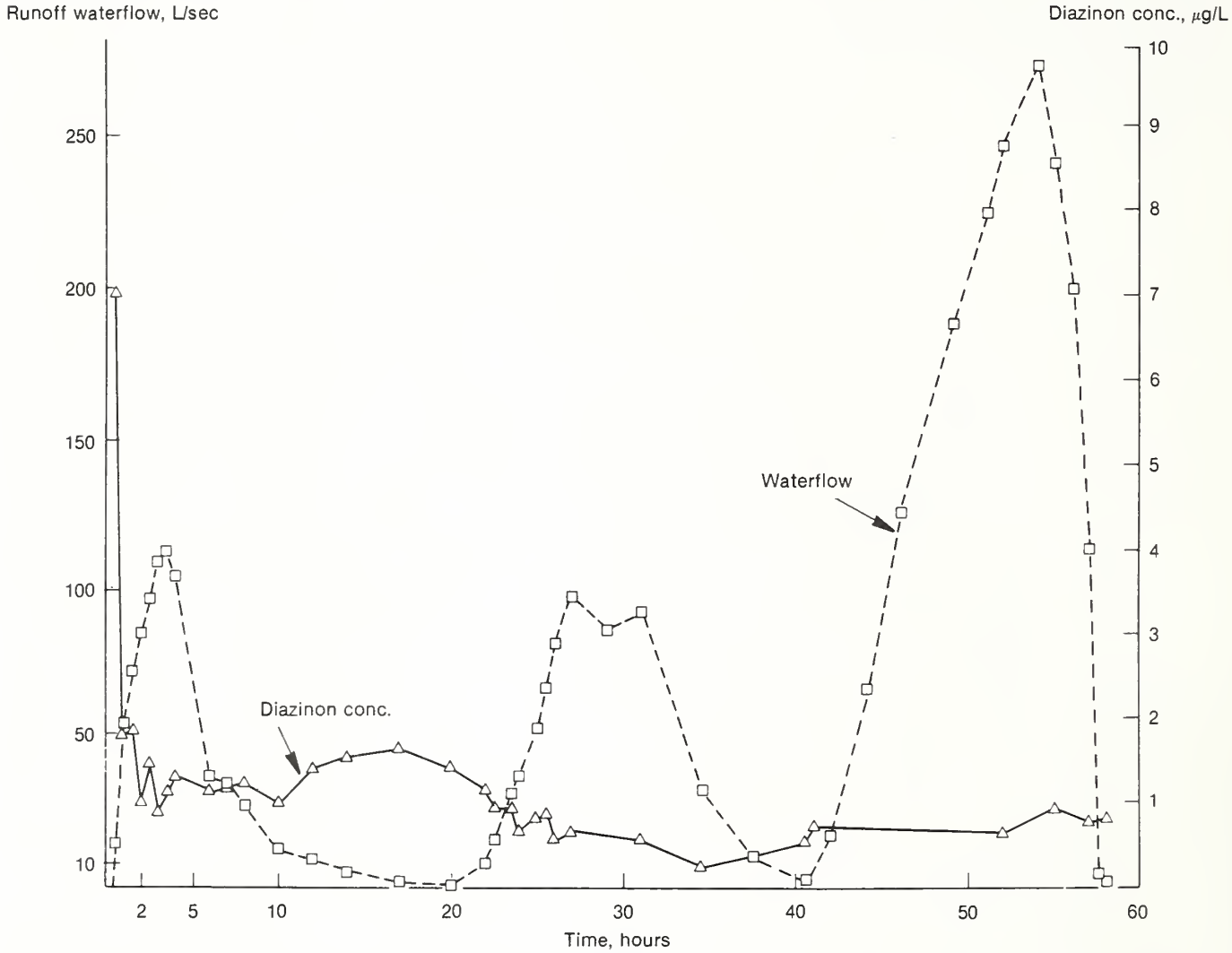


average maximum temperatures during March and August were 24° and 41°C, respectively. Apparently, EPTC runoff is also directly related to the volume of runoff water or irrigation efficiency, and the quantities lost in runoff can be greatly decreased by preventing excess runoff during the application irrigation.

Resin Extracts of Tile Drain Effluents

Eight resin-extracted tile effluent samples representing 30 L each were collected from the tile drain of field 3 in 1980 and 1981. They were extracted, concentrated, and analyzed for all possible pesticides that had been recently applied to the field. The XAD-2 resins used for trapping

Figure 7. — Water runoff hydrograph and diazinon concentrations in runoff from a 60-ha sugarbeet field on November 7-9, 1979, 20 days after diazinon was applied at 0.48 kg/ha.



the pesticides were batch extracted four times with 50 ml of hexane. The combined extracts were then concentrated to 1 ml. All GLC analyses were performed with a 3 percent OV-1 column at 170°C. Using ethyl parathion as a reference, relative retention times were determined for phosphorus, sulfur, and halogenated pesticides using a dual flame photometric detector and an electron capture detector.

The sample extracts were screened and analyzed for the pesticides shown in table 24. When chromatographic peaks with relative retention times similar to those of the known pesticides listed in table 24 were observed, the sample and pesticide standard were examined on a 6-ft, 5 percent QF-1 column at 170°C using the appropriate detector. With this screening procedure, none of the pesticides listed in table 24 could be identified in the tile drain effluent samples at concentrations above minimum detectable levels even though all of them had been used on or near field 3. These minimum detectable levels are based on a 30-L drain water sample, a final extract volume of 1 ml, and a 5 µL injection in the GLC (table 24).

Table 24. — *Minimum detectable levels for pesticides in resin extracts of 30-L tile drain water samples*

Pesticide	Detector	Relative retention time	Minimum detectable[1]
			P/b
Methomyl	S	0.112	<0.002
Mevinphos	P	.198	< .001
Diazinon	P	.530	< .001
Dinitramine	EC	.58	< .001
Methyl parathion	P	.695	< .001
Prometryn	S	.800	< .002
Malathion	P	.95	< .002
Ethyl parathion	P, S, EC	1.00	< .001
Chlorpyrifos	P	1.00	< .001
Fenvalerate	EC	1.01	< .001
DCPA	EC	1.05	< .001
Methidathion	P	1.45	< .001

[1]Minimum detectable in the drain effluents based on 30-L water samples and a final extract volume of 1 ml.

These results indicate that most of the presently used pesticides are not sufficiently persistent, or they are not sufficiently mobile to reach ground water in the relatively heavy soils in Imperial Valley.

Statistical Correlations

Time Elapsed Since Last Pesticide Application vs. Pesticide Runoff. Simple correlation coefficients and linear regression equations relating time elapsed since the last pesticide application to $\log_{10}$ pesticide concentration (C_R, µg/L), $\log_{10}$ amount (A_R, g/ha), concentration, and amount in runoff are shown in tables 25, 26, and 27, respectively. Correlations are shown by individual chemicals, chemical groupings, some chemicals on individual crops, and for all chemicals during first irrigations, subsequent irrigations, and all irrigations. The linear models better fit the data when the log transform mean concentration or amount, rather than mean concentration or amount, was used indicating an approximate first-order decrease in concentration rate with time. The slope of the regression line, *a*, or the so called decay constant can be used to calculate the apparent half-life of the pesticide concentration or amount in runoff by the equation:

$$t_{1/2} = \frac{-0.301}{a}$$

Where *a* is the slope of the regression line in the equation $\log y = a\ t + b$ and *y* is the pesticide concentration, C_R, or amount, A_R, lost in runoff (tables 25 and 26). The apparent concentration or amount at time 0 (C_R° or A_R°) can be calculated as the antilog of the intercept *b* in tables 25 and 26. With organophosphate insecticides, the log C_R or log A_R was highly correlated with time elapsed since the last pesticide application for first irrigations as well as for subsequent irrigations or a combination of all irrigations.

When all irrigations were combined, the linear models for log *C* or A_R vs. time fit the data for most of the herbicides and other pesticides on individual crops. Correlation coefficients were generally decreased when groups of chemicals were combined, that is, all herbicides, or any subgroup within the insecticides. Correlations relating log C_R to time were improved whenever individual pesticides, and even individual pesticide applications on specific crops, were correlated separately. This can be seen when comparing the correlation using all methomyl values with that observed for methomyl on individual crops, (lettuce, sugarbeets, and alfalfa) in tables 25 and 26 for "subsequent" and "all" irrigations. This increased correlation is due to the decrease in the number of variables, other than time, affecting C_R as the analysis changes from chemical groups to individual chemicals or to individual chemicals on a particular crop.

The effect of removing other variables from the correlation of $\log_{10} C_R$ with time is readily apparent with the herbicides, prometryn and DCPA, as indicated in figures 8 to 12. Prometryn and DCPA were applied, either preplant or at midseason to cotton growing on three fields over a 4-yr period. The plot of log C_R vs. time since the last pesticide application for all irrigations is shown in figure 8 with correlation coefficients of 0.641 and 0.680 for prometryn and DCPA, respectively. The scatter of points and the relatively low degree of correlation, even though highly significant statistically, is due to differences in concentrations and rates of change in concentrations associated with different seasons and methods and rates of application. This is apparent in figures 9 to 12 where C_R for prometryn and DCPA are plotted against time for individual seasons or methods of application, that is, preplant or midseason. The correlations are greatly improved, indicating that the relationship between *t* and log C_R better fits the linear model within one field and one crop for any particular method of application of the herbicides.

Variations between fields and years that result in lower correlations for all irrigations are probably due to position availability of the pesticide for solubilization in the irrigation runoff water. This is caused by differences in application techniques or placement from year to year, which influences the amount of the herbicide subjected to being transported in the moving irrigation water. Any differences between fields with the same crop are probably not due to soil differences since the range of soil properties within this study was fairly narrow. The fact that good

Table 25. — *Simple correlation (r) and linear regression coefficients (a,b)*[1] *for* $\log_{10}$ *pesticide concentration in runoff* (C_R, *µg/L) vs. time elapsed since last pesticide application* (t, *days) for first, subsequent, and all irrigations*

Pesticides	First irrigation				Subsequent irrigations				All irrigations			
	n[2]	*r*	*a*	*b*	*n*	*r*	*a*	*b*	*n*	*r*	*a*	*b*
Organophosphates												
Diazinon	7	-0.547	-0.020	0.203	4	0.915*	0.023	-2.561	11	-0.234	-0.006	-0.262
Chlorpyrifos	12	-.469	-.125	.302	5	-.749	-.027	.048	17	-.449	-.029	.006
Malathion	8	-.426	-.069	.757	5	-.834*	-.092	1.67	13	-.620*	-.069	.842
Methidathion	3	-.993**	-.153	2.11	7	-.724*	-.045	.268	10	-.867**	-.062	.990
Sulprofos									3	.263	.270	-.585
Ethyl parathion	10	-.910**	-.038	1.33	11	-.636*	-.014	-.359	21	-.872**	-.025	.889
Methyl parathion	12	-.888**	-.045	.77	7	-.863**	-.028	-.267	19	-.932**	-.039	.594
Pyrethroids												
Permethrin	20	-.193	-.030	-.733	—	—	—	—	23	-.130	-.015	-.784
Fenvalerate	8	.314	.051	-1.133	5	-.684	-.0996	.005	13	-.519*	-.059	-.606
Carbamate												
Methomyl	26	-.447*	-.011	1.409	18	.002	3.877	.063	44	-.574**	-.014	1.236
Organochlorines												
Endosulfan	6	-.924**	-.018	1.58	—	—	—	—	7	-.882**	-.018	1.49
Ethylan	—	—	—	—	—	—	—	—	3	-.992**	-.139	2.270
Herbicides												
Prometryn	7	.584	.188	.868	28	-.551**	-.0189	1.527	35	-.641**	-.0193	1.551
DCPA	6	-.159	-.0043	1.45	29	-.662**	-.011	1.79	35	-.680**	-.0095	1.638
Trifluralin	3	.076	.017	.551	9	-.523	-.022	.75	12	-.601*	-.022	.708
Dinitramine	—	—	—	—	8	-.203	-.0046	.486	10	-.339	-.0067	.615
EPTC	—	—	—	—	18	-.580**	-.024	.499	18	-.580**	-.024	.499
Organophosphates	57	-.447**	-.027	.389	42	-.501**	-.011	-.707	99	-.648**	-.020	.103
Pyrethroids	28	-.013	-.002	-.854	10	-.486	-.007	-1.397	38	-.454**	-.010	-.923
Organochlorines	8	-.753*	-.007	1.220	—	—	—	—	10	-.553	-.006	.927
Herbicides	19	-.095	0.006	1.229	93	-.142	-.003	.542	112	-.274**	-.006	.794
Insecticides	119	-.119	-.004	.205	77	-.254**	-.006	.641	196	-.387**	-.011	.045
Insecticides without pyrethroids	91	-.257**	0.007	.583	67	-.280*	-.007	-.456	158	-.482**	-.013	.370
All pesticides	138	-.140	-.005	.359	170	-.203**	-.006	.076	308	-.272**	-.007	.270
Ethyl parathion												
Lettuce	4	-.994**	-.061	1.75	6	-.656	-.014	-.56	10	-.852**	-.026	.780
Sugarbeets	5	-.964**	-.033	1.30	5	-.666	-.016	.013	10	-.899**	-.025	1.034
Methyl parathion												
Lettuce	6	-.954**	-.059	1.154	4	-.802	-.021	-.830	10	-.915**	-.044	.684
Sugarbeets	5	-.908**	-.036	.724	3	-.967**	-.034	.467	8	-.975**	-.037	.708
Methomyl												
Lettuce	8	-.667*	-.021	1.63	4	-.906*	-.023	1.72	12	-.907**	-.022	1.66
Sugarbeets	6	-.400	-.007	1.441	10	-.721**	-.015	1.733	16	-.869**	-.013	1.533
Alfalfa	11	-.271	-.005	1.265	5	-.846*	-.053	1.591	16	-.592**	-.025	1.281

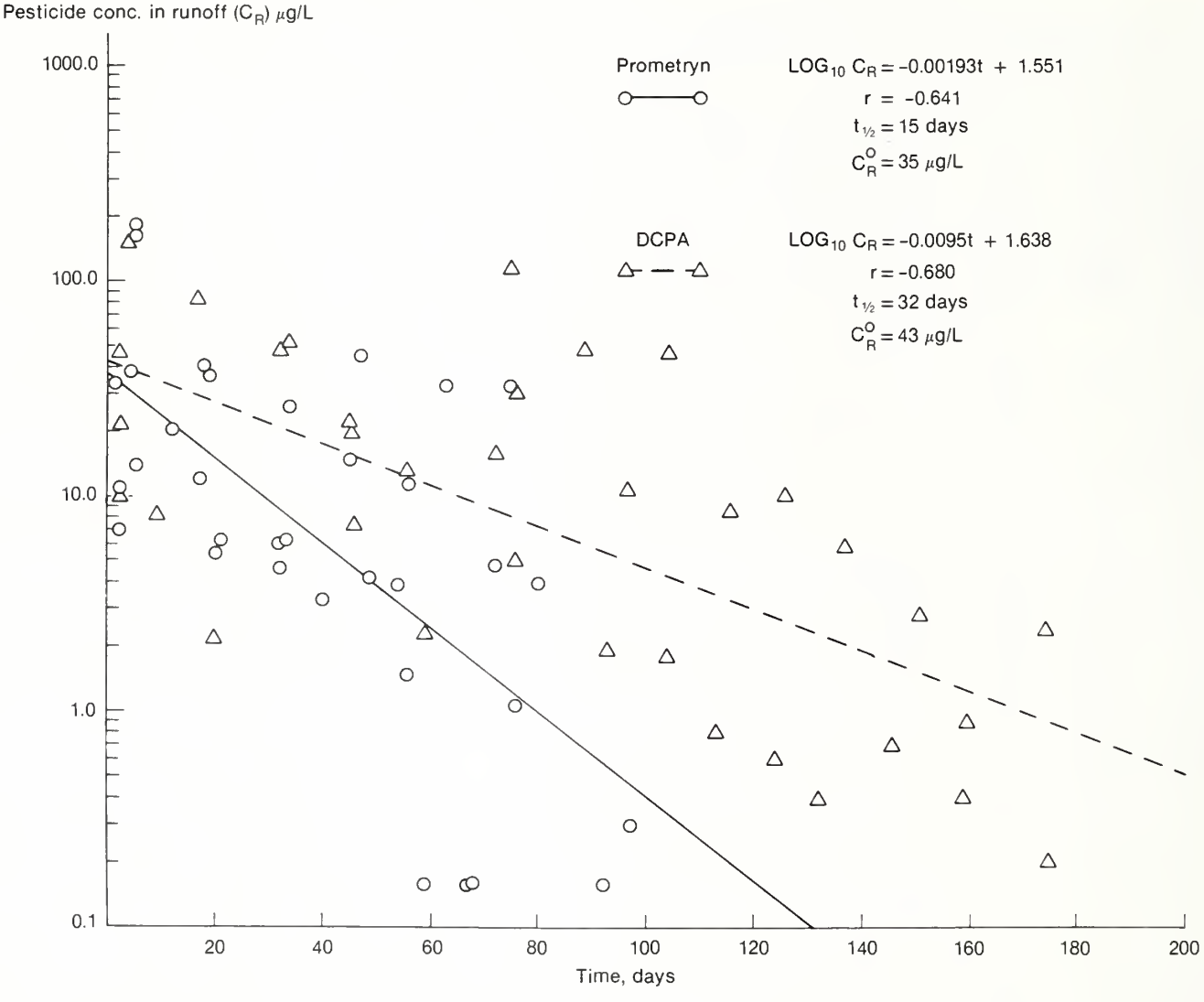
[1] Log $C_R = at + b$.
[2] n = number of observations.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 26. — *Simple correlation (r) and linear regression coefficients*[1] *(a,b) for* $\log_{10}$ *amount of pesticide in runoff* (A_R, *g/ha) vs. time elapsed since last pesticide application* (t, *days) for first, subsequent, and all irrigations*

Pesticides	First irrigation[2]				Subsequent irrigations				All irrigations			
	n[3]	*r*	*a*	*b*	*n*	*r*	*a*	*b*	*n*	*r*	*a*	*b*
Organophosphates												
Diazinon	7	-0.755**	-0.025	-0.416	5	-0.042	-0.0006	-1.957	12	-0.622*	-.013	-0.787
Chlorpyrifos	12	-.343	-.085	-.548	6	-.741*	-.007	-.975	18	-.416	-.009	-.843
Malathion	8	-.504	-.083	-.017	5	-.874**	-.106	1.116	13	-.666**	-.077	.035
Methidathion	3	-.879*	-.130	1.246	7	-.694*	-.040	-.545	10	-.864**	-.059	.271
Sulprofos	3	.406	.415	-1.574	—	—	—	—	3	.406	.415	-1.574
Ethyl parathion	10	-.875**	-.047	.810	11	-.263	-.006	-2.037	21	-.763**	-.025	.058
Methyl parathion	12	-.880**	-.056	.250	7	-.435	-.013	-2.198	19	-.840**	-.040	-.193
Pyrethroids												
Permethrin	20	-.097	-.014	-1.521	3	-.863	-.086	.051	23	.028	.003	-1.566
Fenvalerate	8	.083	.011	-1.469	7	-.070	0.0008	-2.644	15	-.386	-.007	-1.792
Carbamate												
Methomyl	26	-.114	-.003	-.628	23	-.065	-.001	-.772	49	-.582**	-.012	.423
Organochlorines												
Endosulfan	6	-.550	-.008	.679	—	—	—	—	7	-.455	-.008	.529
Ethylan	—	—	—	—	—	—	—	—	3	-.999**	-.172	-1.760
Herbicides												
Prometryn	7	.532	.132	.602	28	-.390*	-.014	.694	35	-.567**	-.018	.930
DCPA	6	-.960**	-.066	1.264	29	-.649**	-.012	1.197	35	-.623**	-.011	.994
Trifluralin	3	-.999**	-.129	.430	9	-.352	-.014	-.386	12	-.544*	-.019	-.122
Dinitramine	—	—	—	—	8	-.013	-.0002	-.089	10	-.370	-.006	.285
EPTC	—	—	—	—	18	-.565*	-.024	-.248	18	-.565**	-.024	-.248
Organophosphates	57	-.511**	-.033	-.267	41	-.388*	-.009	-1.652	98	-.615**	-.020	-.656
Pyrethroids	28	-.025	-.004	-1.518	10	-.299	-.055	-2.044	38	-.373*	-.004	-1.598
Organochlorines	8	-.777*	-.007	.483	—	—	—	—	10	-.526	-.006	.106
Herbicides	19	-.746**	-.056	1.007	93	-.125	-.003	-.136	112	-.284**	-.007	.180
All pesticides	138	-.184*	-.007	-.305	169	-.143	-.004	-.723	307	-.250**	-.007	-.442
Ethyl parathion												
Lettuce	4	-.992**	-.077	1.330	6	-.165	-.004	-2.624	10	-.702*	-.026	-.231
Sugarbeets	5	-.992**	-.040	.854	5	-.568	-.012	-1.027	10	-.878**	-.024	.429
Methyl parathion												
Lettuce	6	-.953**	-.073	.725	4	.047	.001	-3.411	10	-.788**	-.046	-.193
Sugarbeets	5	-.969**	-.045	.268	3	-.963**	-.028	-.709	8	-.974**	-.038	.115
Methomyl												
Lettuce	8	.025	.001	.63	4	.369	.005	-1.406	12	-.620*	-.016	.694
Sugarbeets	6	-.193	-.006	.703	10	-.706*	-.015	1.124	16	-.830**	-.013	.815
Alfalfa	11	-.209	-.005	.536	5	-.913**	-.055	.747	16	-.582*	-.027	.544

[1] Log $A_R = at + b$.
[2] First irrigation after a pesticide application.
n = number of observations.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Figure 8. — Relationship between concentrations of prometryn and DCPA in runoff water and the time elapsed since the last pesticide application for all fields and all irrigations.



correlations were observed between runoff concentrations and soil concentrations within the irrigation furrow supports the position availability premise that it is the soil concentration in the wetted perimeter of the furrow that controls the runoff concentration. This, in turn, is related to the time elapsed since the last pesticide application as well as to the method of application and other factors affecting amounts of pesticide within the wetted soil area.

The disturbance of the banded preplant application of DCPA by a midseason cultivation was reflected in increased DCPA concentrations in runoff water (fig. 12). DCPA was applied preplant at 3.6 kg/ha as a banded application in the top of the beds. Runoff concentrations were low until a cultivation on day 67 carried treated soil down the bed surfaces and into the furrows, resulting in much higher concentrations of DCPA throughout the remainder of the growing season.

The insecticides, which were mainly applied by airplane, did not appear to be affected as much by other variables as did the herbicides. This was probably due, in part, to the similar method of applying all insecticides regardless of crop, year, or management practice. This is illustrated

in figure 13, which shows the relationship between C_R for ethyl and methyl parathion and time elapsed since application for all irrigations regardless of crop or year of sampling. The linear regression model indicated a correlation coefficient, r, of 0.872 and 0.932 with $t_{1/2}$ of 12 and 7.7 days for ethyl and methyl parathion, respectively.

The correlation between time elapsed since the last pesticide application and concentrations or amounts in runoff (table 27) was lower than for the $\log_{10}$ concentrations and $\log_{10}$ amounts. This indicates that the relationship between t and C_R or A_R is nonlinear and follows an approximate first-order rate of decrease in concentration or amount with time.

Accumulative Water Applied vs. Pesticide Runoff. Multiple regression was used to determine the relationship between $\log_{10} C_R$ and the two independent variables, time (t) and accumulative water applied (W_c) since the last pesticide application. The multiple linear regression of log C_R vs. t and W_c is shown in table 28. The addition of the variable, W_c, to the variable t appeared to slightly improve the predictability of log C_R *as the* R^2 values were slightly improved and more of them were highly significant. The analysis indicated that t was still the dominant variable, but W_c did contribute to the decrease in pesticide concentration in runoff.

The simple linear regressions for W_c, log C_R and C_R for all irrigations are shown in table 29. Here again, W_c was more highly correlated with the log C_R than with C_R, indicating a nonlinear relationship between W_c and pesticide concentration in runoff.

Runoff Volume vs. Pesticide Runoff. Correlations between C_R or A_R and runoff volume (V_R) were very low and generally insignificant (table 30). The lack of correlation between water runoff volume and pesticide amounts lost in runoff was somewhat surprising but is probably caused by the many other variables affecting amounts of pesticides lost during an irrigation event, such as time elapsed and the number of irrigations since the last pesticide application, along with the usual differences caused by soil, crop, and pesticide management practices.

Figure 9. — Relationship between prometryn concentrations in runoff water and time elapsed since the preplant or midseason prometryn application on field 1 in 1980.

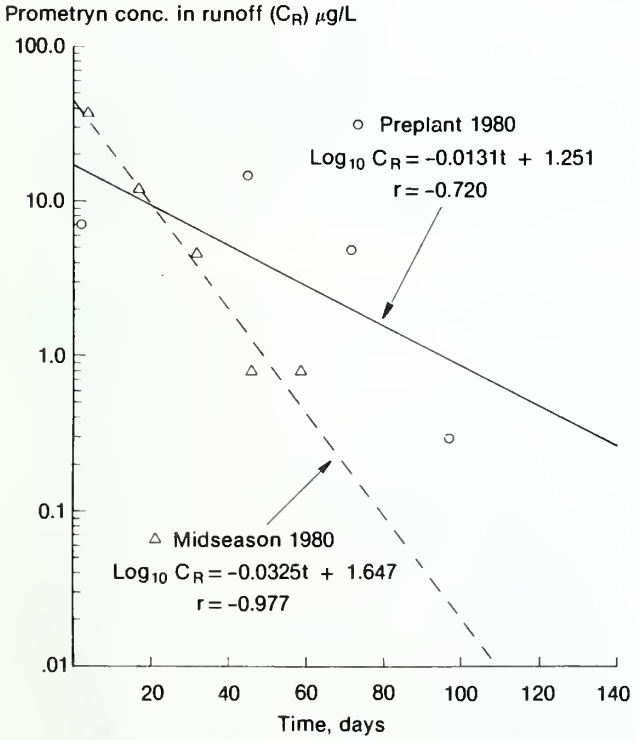


Figure 10. — Relationship between prometryn concentration in runoff water and time elapsed since the preplant or midseason application to field 1 in 1981.

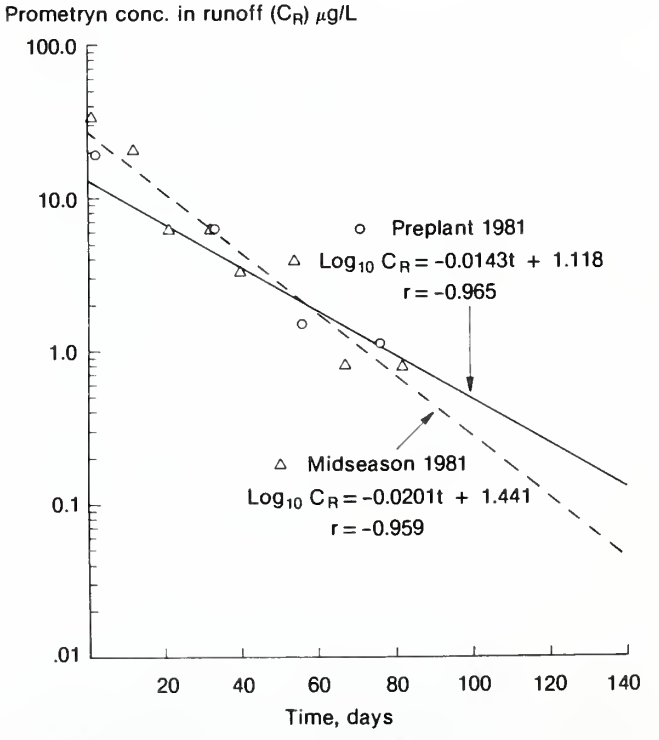
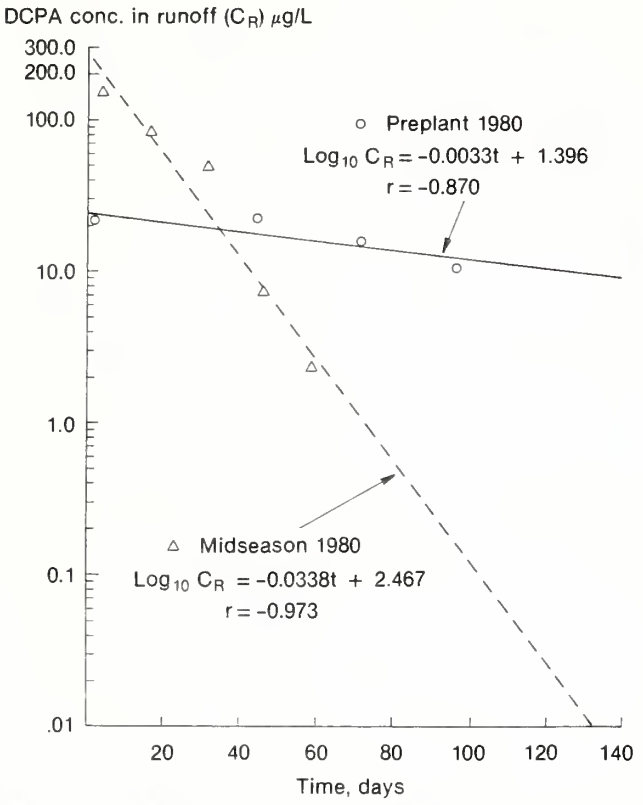


Figure 11. — Relationship between DCPA concentration in runoff water and time elapsed since the preplant or midseason DCPA application to field 1 in 1980.



The effect of increasing runoff volumes on amounts of pesticides lost from individual fields and crops can be readily seen, however, when comparing subsequent irrigations on the same field or split irrigations following a pesticide application. For example, runoff of methomyl was greatly increased by increasing runoff volumes in consecutive irrigations on field 4 in 1979 (table 15). The runoff event on October 7 to 9 with a runoff of 2.4 cm resulted in a loss of 6.2 g/ha methomyl. The runoff event of October 28 to 30, 1979, with a runoff volume of 0.9 cm, resulted in a loss of only 1.5 g/ha methomyl even though the mean concentrations of methomyl in the runoff water were somewhat similar for both irrigations.

The effect of water volume on methomyl runoff from a small lettuce field following three applications of methomyl was determined in 1979 (table 22) by applying 12 cm of irrigation water to one-half of the field and 22 cm to the other half 44 days after the last methomyl application. The 22-cm irrigation resulted in considerably more runoff water and loss of methomyl than the 12-cm irrigation with maximum and mean concentrations of methomyl, total amounts, and percent of applied in runoff being considerably greater with the higher runoff volume. With 22 and 12 cm applied water, 11.2 and 3.6 g/ha methomyl were lost in runoff, respectively. When all runoff events are combined in an overall correlation of runoff volume with pesticide runoff, these relationships disappear because of the many other factors affecting amounts of pesticide lost during any individual irrigation runoff event.

Sediment vs. Pesticides in Runoff. The concentrations of sediment in runoff water and amounts of sediment lost in runoff for individual irrigations are shown in appendix tables 7 and 8. Correlations of concentrations and amounts of pesticides in runoff with sediment concentrations and amounts of runoff for all irrigations are shown in table 31. For most of the pesticides, the correlations between concentrations or amounts of pesticides and sediment were relatively poor. The appearance of highly significant correlation coefficients for a few pesticides apparently is a fortuitous circumstance related to the low numbers of samples used in the correlations. There appeared to be very little relationship between the few observed high correlation coefficients and water solubility or adsorption coefficient of the pesticide. Even compounds like fenvalerate, which are associated with sediment more than with water, did not exhibit a significant correlation coefficient relating sediment to pesticides in runoff.

The correlation between sediment and pesticides in runoff appeared to be better for herbicides than insecticides. This is probably a result of herbicide incorporation into the soil compared with aerial application of insecticides. Herbicides would tend to be present in runoff in greater amounts whenever the irrigation water eroded greater amounts of soil.

Soil Concentrations and Pesticide Runoff. A highly significant correlation was observed between concentrations of pesticides in the 0- to 1-cm soil depth (appendix tables 1-6) and concentrations and amounts of pesticides in runoff water. Table 32 shows the correlation coefficients and linear regression equations expressing the relationship between log pesticide concentration in runoff (log C_R) vs. log soil concentration (log C_S) and pesticide concentration in runoff water (C_R) vs. the soil concentration (C_S). Highly significant correlations were observed for most of the pesticides and pesticide groups with the exception of the pyrethroids and organochlorine insecticides. The lack of correlation between pyrethroid concentrations in soil and runoff appears to be due to the erratic runoff behavior of the pyrethroids, which caused the linear regressions to be influenced by one or two abnormally high

pyrethroid concentrations in runoff water when soil concentrations were low.

The correlations by individual pesticides were better than correlations of combined herbicides or insecticides. Figures 14 to 18 illustrate the relationship between log concentration in runoff water and log concentration in soil and the better correlation for individual than for groups of chemicals. The data indicate that the concentrations and amounts of pesticides in the 0- to 1-cm depth of soil are good indicators of the concentrations and amounts of pesticides to be expected in runoff water under furrow irrigation systems such as those used in Imperial Valley.

Persistence of Pesticides in Soil. Simple linear regressions relating time since the last pesticide application to log concentration or log amounts of pesticides in the 0- to 1-cm depth of soil were used to calculate degradation constants for pesticides in the soil. The relationship between elapsed time and $\log_{10}$ concentration (log C_S),

Figure 12. — Relationship between DCPA concentration in runoff water and time elapsed since the last preplant application of DCPA to fields 1 and 3 in 1981. A preplant application to field 3 was disturbed by a midseason cultivation at day 67, resulting in a marked increase in the concentration of DCPA. The linear regression does not include the data points prior to day 67.

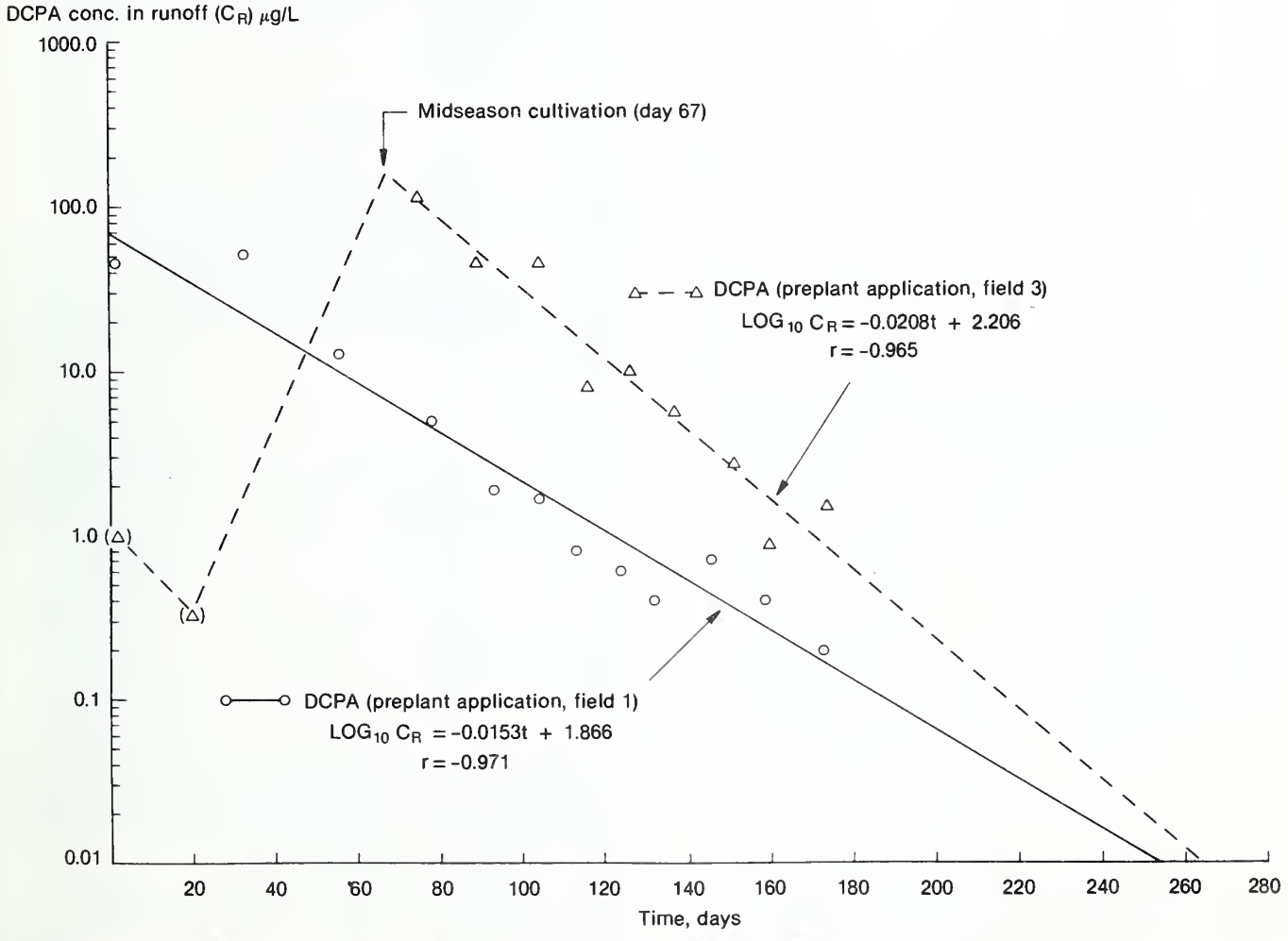
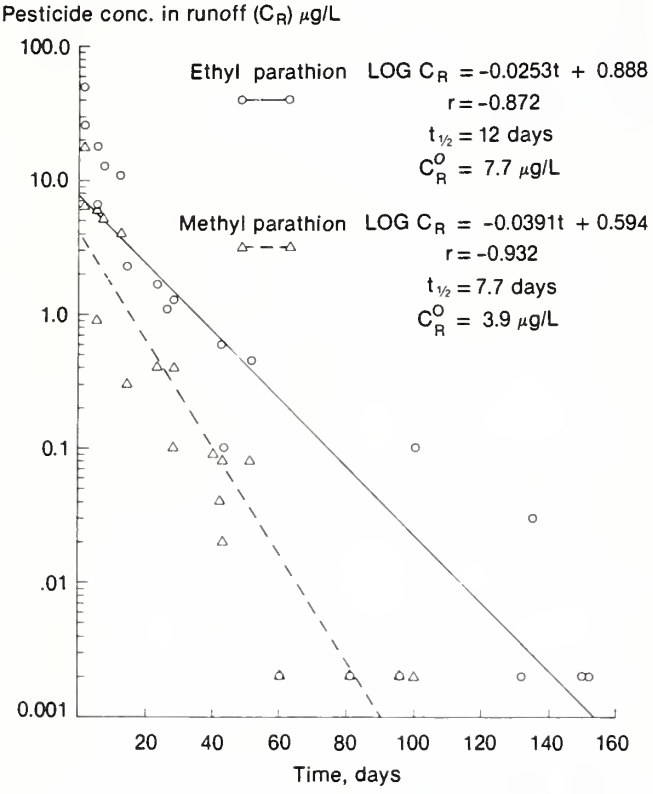


Figure 13. — Relationship between concentrations of ethyl and methyl parathion and time elapsed since the last pesticide application for all fields and all irrigations.



amounts (log A_S), and percent (log percent) of total applied pesticide remaining in soil at the time of sampling are shown in tables 33 and 34. With most pesticides, the decrease in concentration followed a first-order rate with highly significant correlation coefficients between time and log concentration or log amount remaining in the soil. The apparent half-life ($t_{½}$) and estimated concentration at time 0 (C_S^o) are also shown in table 33. The data are useful for developing predictive capabilities for estimating pesticides remaining in the soil and, consequently, concentrations and amounts in runoff. The degradation constant or half-life in soil includes all routes of dissipation from the 0- to 1-cm depth zone, such as volatilization, leaching, and biological or chemical degradation.

Analytical Quality Assurance Study

Pesticide concentrations in samples of irrigation runoff water as determined by four laboratories are shown in table 35. All laboratories analyzed the water samples for the organophosphate insecticides methidathion, ethyl parathion, and methyl parathion (not all samples were analyzed for each pesticide by all laboratories). Other pesticides were analyzed by the individual laboratories if they had the analytical capability and time to do so. The results, with a few exceptions, indicate very good agreement among the various laboratories for the analysis of most of the pesticides, particularly the organophosphate insecticides, in the runoff water samples. Ethyl and methyl parathion were not detectable in samples 5, 6, 7, and 8 by laboratory IV, which was probably caused by degradation of the ethyl and methyl parathion in the high pH water during storage. Laboratory IV had stored the samples at 4°C for at least 4 weeks prior to extraction. These particular samples were those in which we had experienced degradation problems from the high pH of the water due to anhydrous ammonia addition to the sugarbeets.

A much more comprehensive study would have been desirable; however, the limited data available from this study give us confidence that our laboratory results on pesticides in irrigation runoff water are reasonably accurate considering the very low concentrations in the parts per billion range or less.

Minimum Sampling Frequency for Estimating Total Pesticide Losses

The relationship between pesticide concentrations and the water runoff hydrograph was examined from the standpoint of possibly reducing the sampling frequency necessary to accurately estimate the total pesticide runoff during an irrigation event. For this purpose, total pesticide runoff was calculated using various combinations of sampling times with respect to the water runoff hydrograph.

A comparison of pesticide losses in several irrigation runoff events on different fields, calculated using average concentrations during peak flows versus the full integration method as previously described, is shown in table 36. The calculations indicate that in most cases total pesticide runoff could have been accurately estimated using pesticide concentration data from only the peak flows. For most accurate estimates, the concentrations and flow volumes for each peak must be considered, that is, the average concentration of samples taken during the first peak flow must be multiplied by the runoff volume during that peak and added to the average concentrations times the runoff volume from subsequent peaks to arrive at the total amount of runoff. For example, runoff of methomyl from field 4 on October 7 to 9, 1979 (fig. 6), was estimated to be 6.2 g/ha using 24 data points taken over the entire irrigation period. The irrigation runoff event had two periods of peak flow. Using the average of three concentrations of methomyl from each flow peak and the flow

Text continues on p. 50

Table 27. — *Simple correlation (r) and linear regression coefficients for mean concentration (C_R, µg/L) and amounts (A_R, g/ha) for pesticides in runoff vs. time elapsed (t, days) since the last pesticide application for all irrigations*

	Concentration, C_R vs. t[1]				Amount, A_R vs. t[2]			
Pesticides	***n***	***r***	***a***	***b***	***n***	***r***	***a***	***b***
Organophosphates								
Diazinon	12	-0.469	-0.032	3.243	12	-0.529	-0.004	0.423
Chlorpyrifos	19	-.377	-.017	1.832	19	-.378	-.003	.334
Malathion	13	-.519*	-.249	8.795	13	-.499	-.026	.945
Methidathion	10	-.654*	-.130	5.510	10	-.666*	-.028	1.18
Sulprofos	3	-.045	-.065	1.030	5	-.692	-.001	.147
Ethyl parathion	21	-.524*	-.123	13.16	21	-.532**	-.037	3.94
Methyl parathion	19	-.535*	-.077	4.949	19	-.540*	-.023	1.45
Pyrethroids								
Permethrin	23	-.049	-.006	.376	23	.029	.001	.060
Fenvalerate	15	-.357	-.001	.223	18	-.368	-.0003	.058
Carbamate								
Methomyl	49	-.479**	-.216	24.26	49	-.486**	-.039	4.73
Organochlorines								
Endosulfan	7	-.567	-.393	36.51	7	-.414	-.082	7.78
Ethylan	3	-.992**	-.242	5.353	3	-.980**	-.029	.632
Herbicides								
Prometryn	35	-.421**	-.603	46.00	38	-.251	-.046	8.42
DCPA	35	-.471**	-.297	47.00	36	-.575**	-.082	12.54
Trifluralin	12	-.664*	-.077	5.276	12	-.639*	-.013	.865
Dinitramine	10	-.399	-.065	6.808	10	-.437	-.027	2.82
EPTC	18	-.349	-.073	4.521	18	-.367	-.013	.808
Organophosphates	99	-.321**	-.054	4.871	99	-.281**	-.013	1.169
Pyrethroids	38	-.136	-.002	.308	38	-.154	-.0004	.064
Organochlorines	10	-.400	-.108	24.66	10	-.314	-.023	5.247
Herbicides	112	-.219*	-.157	22.92	112	-.230*	-.047	6.350
All pesticides	308	-.166**	-.081	12.68	317	-.156**	-.017	3.01
Ethyl parathion								
Lettuce	10	-.489	-.150	15.29	10	-.492	-.043	4.41
Sugarbeets	10	-.702*	-.115	13.09	10	-.702*	-.037	4.16
Methyl parathion								
Lettuce	10	-.590*	-.126	7.179	10	-.600*	-.037	2.13
Sugarbeets	8	-.718*	-.055	4.270	8	-.723*	-.016	1.246
Methomyl								
Lettuce	12	-.542*	-.503	42.16	12	-.513	-.067	6.810
Sugarbeets	16	-.819**	-.181	25.13	16	-.660**	-.040	5.57
Alfalfa	16	-.511*	-.403	22.22	16	-.487*	-.081	4.450

[1] $C_R = a\,t + b$.
[1] $A_R = a\,t + b$.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 28. — *Multiple linear regression[1] of log_{10} pesticide concentration (C_R, µg/L) vs. time elapsed (t, days) and accumulative water applied (W_C, cm) since the last pesticide application for subsequent and all irrigations*

	Subsequent irrigations						All irrigations					
Pesticides	***n***	***R^2***	***R***	***a_1***	***a_2***	***b***	***n***	***R^2***	***R***	***a_1***	***a_2***	***b***
Organophosphates												
Diazinon	5	0.581	0.762*	0.004	-0.068	-0.135	12	0.357	0.598*	-0.009	-0.044	0.483
Chlorpyrifos	7	.713	.844**	-.009	-.006	-.215	19	.355	.596**	-.009	-.014	.059
Malathion	5	.805	.897**	-.014	-.053	.981	13	.393	.627*	-.056	-.012	.815
Methidathion	7	.536	.732*	-.051	-.005	.209	10	.768	.877**	-.063	.001	.983
Ethyl parathion	11	.450	.671*	-.008	-.025	-.229	21	.762	.873**	-.024	-.005	.931
Methyl parathion	7	.747	.864**	-.026	-.008	-.175	19	.869	.932**	-.039	-.002	.616
Pyrethroids												
Permethrin	—	—	—	—	—	—	23	.020	.141	-.019	.005	-.834
Fenvalerate	7	.148	.385	-.002	-.016	-1.351	15	.603	.777**	.003	-.065	.175
Carbamate												
Methomyl	23	.466	.683**	-.0004	-.034	1.115	49	.718	.847**	-.003	-.042	1.696
Organochlorines												
Endosulfan	—	—	—	—	—	—	7	.793	.891**	-.040	.042	1.301
Herbicides												
Prometryn	28	.305	.552**	-.021	.003	1.456	35	.411	.641**	-.018	-.001	1.572
DCPA	29	.800	.894**	.002	-.022	2.021	35	.753	.868**	.002	-.021	1.865
Trifluralin	9	.386	.621	.017	-.058	1.786	12	.484	.696**	.020	-.059	1.646
Dinitramine	8	.101	.317	-.022	.022	.075	10	.116	.340	-.004	-.003	.668
EPTC	18	.474	.689**	-.027	-.008	1.148	18	.474	.689**	-.027	-.008	1.148
All pesticides	170	.050	.224**	-.006	.004	-.078	308	.074	.272**	-.007	-.0002	.274
Ethyl parathion												
Lettuce	6	.431	.656	-.009	-.013	-.602	10	.830	.911**	-.063	.112	.315
Sugarbeets	5	.698	.836*	-.002	-.114	1.549	10	.849	.921**	-.015	-.069	1.740
Methyl parathion												
Lettuce	4	.893	.945**	.048	-.212	-.719	10	.845	.919**	-.048	.018	.590
Sugarbeets	—	—	—	—	—	—	8	.963	.982**	-.033	-.036	1.115
Methomyl												
Lettuce	4	.893	.945**	.007	-.073	1.803	12	.841	.917**	-.013	-.027	1.804
Sugarbeets	10	.520	.721**	-.015	-.0001	1.733	16	.757	.870**	-.011	-.008	1.589
Alfalfa	5	.758	.871*	.073	.058	.862	16	.721	.849**	.004	-.107	2.382

[1] Log $C_R = b + a_1 t + a_2 W_C$.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 29. — *Simple correlation (r) and linear regression coefficients for mean concentration (C_R, µg/L) and log C_R vs. accumulative water applied (W_C, cm) for all irrigations*

	C_R vs. W_C[1]				C_R vs. W_C[2]			
Pesticides	***n***	***r***	***a***	***b***	***n***	***r***	***a***	***b***
Organophosphates								
Diazinon	12	-0.365	-0.113	3.46	12	-0.464	-0.050	0.131
Chlorpyrifos	19	-.423	-.053	2.49	19	-.479*	-.029	.138
Malathion	13	-.388	-.145	6.39	13	-.537*	-.047	.292
Methidathion	10	-.621*	-.076	5.10	10	-.707*	-.031	.568
Sulprofos	3	-.117	-.070	1.751	3	.193	.082	-1.171
Ethyl parathion	21	-.330	-.299	12.47	21	-.759**	-.085	1.229
Methyl parathion	19	-.129	-.080	3.34	19	-.551**	-.101	.607
Pyrethroids								
Permethrin	23	-.046	-.004	.399	23	-.030	-.002	-.839
Fenvalerate	15	-.652**	-.011	.462	15	-.769**	-.057	.051
Carbamate								
Methomyl	49	-.540**	-.718	30.79	49	-.840**	-.048	1.705
Organochlorines								
Endosulfan	7	-.736	-.717	39.16	7	-.861**	-.034	1.631
Ethylan	3	-.432	-.151	1.665	3	-.646	-.130	.386
Herbicides								
Prometryn	35	-.428**	-.803	57.99	35	-.589**	-.023	1.822
DCPA	35	-.546**	-.515	51.68	35	-.865**	-.019	1.884
Trifluralin	12	-.761**	-.120	7.44	12	-.677**	-.033	1.290
Dinitramine	10	-.461	-.086	8.61	10	-.337	-.008	.737
EPTC	18	-.130	-.014	3.47	18	-.224	-.005	.175
Organophosphates	99	-.231*	-.096	4.884	99	-.492**	-.037	.145
Pyrethroids	38	-.203	-.010	.466	38	-.572**	-.040	-.304
Organochlorines	10	-.281	-.410	24.72	10	-.346	-.019	.898
Herbicides	112	-.362**	-.358	33.56	112	-.494**	-.014	1.250
All pesticides	317	-.165**	-.130	13.40	—	—	—	—
Ethyl parathion								
Lettuce	10	-.283	-.254	12.46	10	-.738**	-.066	.805
Sugarbeets	10	-.545	-.556	16.68	10	-.879**	-.150	2.360
Methyl parathion								
Lettuce	10	-.029	-.019	2.53	10	-.526	-.079	.031
Sugarbeets	8	-.481	-.235	5.835	8	-.713*	-.174	1.985
Methomyl								
Lettuce	12	-.543*	-1.347	48.35	12	-.901**	-.059	1.923
Sugarbeets	16	-.756**	-.699	28.65	16	-.848**	-.054	1.857
Alfalfa	16	-.694**	-1.487	37.64	16	-.847**	-.098	2.327

[1] $C_R = a\ W_C + b$.
[2] log $C_R = a\ W_C + b$.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 30. — *Simple correlation (r) and linear regression coefficients for mean concentration (C_R, µg/L) and amounts (A_R, g/ha) of pesticides in runoff vs. water runoff volume (V_R, cm) for all irrigations*

Pesticides	C_R vs. V_R[1]				A_R vs. V_R[2]			
	n	*r*	*a*	*b*	*n*	*r*	*a*	*b*
Organophosphates								
Diazinon	12	-0.344	-0.752	3.27	12	-0.225	-0.059	0.336
Chlorpyrifos	19	-.373	-.576	2.84	19	-.269	-.072	.441
Malathion	13	-.099	-.961	5.03	13	-.055	-.058	.502
Methidathion	10	-.174	-.238	2.62	10	-.120	-.034	.514
Sulprofos	5	-.454	-.050	.825	5	-.457	-.007	.127
Ethyl parathion	21	.228	1.92	1.78	21	.288	.723	.176
Methyl parathion	19	.358	1.23	-.315	19	.397	.398	-.175
Pyrethroids								
Permethrin	23	-.159	-.064	.493	23	.057	.004	.055
Fenvalerate	18	-.115	-.011	.190	18	.031	.001	.038
Carbamate								
Methomyl	49	-.167	-1.61	18.92	49	.326*	.563	1.60
Organochlorines								
Endosulfan	7	-.381	-1.63	33.89	7	-.059	-.072	6.10
Ethylan	3	.757	1.33	-.028	3	.803	.173	-.026
Herbicides								
Prometryn	38	-.085	-1.33	24.72	38	.247	1.204	1.87
DCPA	36	.022	.565	20.61	36	.322	2.01	.565
Trifluralin	12	-.420	-.776	4.61	12	.431	.137	.124
Dinitramine	10	-.391	-.507	6.97	10	-.141	-.069	2.11
EPTC	18	-.097	-.703	3.84	18	.036	.045	.366
Organophosphates	101	.002	.005	2.913	101	.072	.063	.544
Pyrethroids	41	-.139	-.039	.360	41	.030	.001	.050
Organochlorines	49	-.167	-1.606	18.92	49	.326*	.563	1.603
Herbicides	116	-.047	-.651	16.45	116	.198*	.783	1.623
All pesticides	317	-.035	-.329	10.07	317	.166**	.421	1.14
Ethyl parathion								
Lettuce	10	.225	2.059	2.188	10	.244	.639	.527
Sugarbeets	10	.217	1.856	1.389	10	.343	.936	-.539
Methyl parathion								
Lettuce	10	.477	2.232	-1.457	10	.500	.682	-.467
Sugarbeets	8	.176	.421	1.240	8	.278	.195	.161
Methomyl								
Lettuce	12	-.396	-3.372	36.83	12	.327	.393	2.863
Sugarbeets	16	.021	.348	11.11	16	.295	1.351	-.360
Alfalfa	16	427	10.73	-4.723	16	.572*	3.035	-2.535

[1] $C_R = a\ V_R + b$.
[2] $A_R = a\ V_R + b$.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 31. — *Simple correlation (r) and linear regression coefficients for pesticide concentration (C_R, µg/L) and amounts (A_R, g/ha) vs. sediment concentration (S_C, g/L) and sediment amounts (S_A, kg/ha) for all irrigations*

	C_R vs. S_C[1]				A_R vs. S_A[2]			
Pesticides	***n***	***r***	***a***	***b***	***n***	***r***	***a***	***b***
Organophosphates								
Diazinon	4	0.760	3.79	-2.99	4	0.992**	-0.025	-4.446
Chlorpyrifos	17	-.424	-1.774	2.980	17	-.459*	-.0008	.459
Methidathion	8	.151	1.801	1.339	8	.320	.004	.096
Sulprofos	3	.920*	3.84	-.404	3	.918*	.005	-.154
Ethyl parathion	19	-.036	-.64	7.34	19	.171	.004	1.353
Methyl parathion	15	-.080	-.484	3.160	15	.078	.0007	.691
Pyrethroids								
Permethrin	16	-.363	-.585	.883	16	-.291	-.0002	.106
Fenvalerate	12	.173	.056	.105	12	.457	8.873	.016
Carbamate								
Methomyl	35	-.092	-3.488	20.60	35	.108	.003	2.877
Organochlorines								
Endosulfan	3	.914*	159.54	-38.56	3	.999**	.113	-2.322
Herbicides								
Prometryn	35	.359*	31.59	-5.942	35	.394*	.019	.550
DCPA	32	.480**	36.97	-7.634	32	.493**	.024	.712
Trifluralin	10	.554	4.11	.379	10	-.047	-.0006	.504
Dinitramine	10	.822**	7.72	-2.34	10	.287	.001	1.085
EPTC	12	-.098	-.776	3.763	12	-.280	-.003	.924
Organophosphates	69	-.041	-.469	3.705	69	.024	.0003	.839
Pyrethroids	28	-.271	-.352	.595	28	-.161	-8.030	.072
Organochlorines	3	.914*	159.5	-38.56	3	.999**	.113	-2.322
Herbicides	101	.368**	24.65	-3.679	101	.361**	.014	.958
All pesticides	236	.152*	6.580	5.515	236	.288**	.009	.763
Ethyl parathion								
Lettuce	10	-.070	-1.41	7.35	10	.049	.001	1.696
Sugarbeets	9	.0081	.11	7.19	9	.473	.014	-0.481
Methyl parathion								
Lettuce	8	-.080	-.58	3.18	8	.012	.0001	.822
Sugarbeets	7	-.090	-.365	3.083	7	400	.003	.103
Methomyl								
Lettuce	9	-.272	-12.36	37.78	9	-.164	-.004	4.754
Sugarbeets	13	.461	9.032	6.752	13	.744**	.028	-1.214
Alfalfa	8	.059	5.15	15.57	8	.390	.033	.418

[1] $C_R = a\ S_C + b$.
[2] $A_R = a\ S_A + b$.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 32. — *Simple correlation (r) and linear regression coefficients for log runoff* (C_R, ug/L) *vs. log soil concentration* (C_S, μg/g) and runoff concentration (C_R) *vs. soil concentration* (C_S) *in the 0 - 1 cm depth zone*

	Log C_R vs. log C_S[1]				C_R vs. C_S[2]			
Pesticides	*n*	*r*	*a*	*b*	*n*	*r*	*a*	*b*
Organophosphates								
Methidathion	3	0.711	1.524	1.711	3	0.984**	154.5	-8.330
Ethyl parathion	6	.996**	1.425	.727	6	.988**	8.646	-1.572
Methyl parathion	6	.952**	1.074	.732	6	.965	5.55	.119
Pyrethroids								
Permethrin	7	-.299	-.486	-.806	7	-.373	-.613	1.167
Fenvalerate	4	-.724	-1.892	-3.252	4	-.643	-2.180	.987
Carbamate								
Methomyl	10	.954**	1.163	1.164	10	.834**	23.73	-4.770
Herbicides								
Prometryn	12	.845**	.572	1.355	12	.501	8.689	15.71
DCPA	8	.921**	1.113	1.049	8	.824**	4.911	24.80
Trifluralin[3]	4	.999**	.715	.702	4	.999**	3.287	1.563
Dinitramine	3	.991**	1.226	1.035	3	.999**	10.48	-.339
Organophosphates	20	.516*	.738	.371	20	.380	6.938	2.363
Pyrethroids	11	-.109	-.232	-1.192	11	-.296	-.476	.864
Herbicides	30	.655**	.770	.998	30	.687**	5.678	13.21
Insecticides	41	.580**	.975	.324	41	.772**	17.45	-4.929
Insecticides without pyrethroids	33	.670**	.948	.666	33	.678**	16.74	-2.103
All pesticides	74	.532**	.862	.585	74	.661**	6.324	7.289

[1] Log $C_R = a \log C_S + b$.
[2] $C_R = a\ C_S + b$.
[3] Trifluralin on cotton only.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

volumes under the peaks, resulted in a calculated runoff of 6.1 g/ha methomyl, which was within ±2 percent of the integrated estimate (table 15).

Other runoff events in table 36 provide similar comparisons with most of them providing estimates within ±16 percent of the integrated value when using only concentrations and runoff volumes measured during each peak flow period. The calculations indicate that both the pesticide concentration and the water volume for each peak of water flow must be considered. Merely averaging the concentrations from the first, second, and third peak and multiplying by the total runoff volume results in much less accurate estimates. In addition, using an average concentration from only the first peak, or any other subsequent peak, times the total runoff volume usually results in serious errors in estimating total pesticide runoff.

These results agree with those for rainfall runoff reported by Frere (*1971*). He stated ". . . the mean concentration of representative samples at each high water flow times the volume of water transported during that flow is an adequate estimate of the amount of constituent transported." This appears to hold also under irrigated conditions when two or more peaks may occur during a runoff event. This indicates that samples only need to be taken during peak flow periods to estimate total pesticide runoff during an irrigation event under many conditions. A probable exception to this is irrigation events following the application of pesticides to the soil surface, such as a directed

spray with a postemergent herbicide like prometryn to cotton. For example, the runoff event of July 24 to 26, 1979, on field 1 followed the application of prometryn at midseason to cotton and resulted in approximately 8 percent runoff of the applied pesticide during the first irrigation event (fig. 1 and table 5). In a situation such as this, the first runoff water contains exceedingly high concentrations of the pesticide, and sampling only peak flows in such cases may miss a significant part of the runoff and underestimate the total pesticide loss by as much as 45 to 50 percent. The data indicate, however, that the pesticide flux or rate of loss curve during a runoff event generally follows the water loss curve of the hydrograph, indicating that waterflow volume is more important than pesticide concentration in controlling the amount of loss for that event.

Sediment Characterization and Partitioning of Pesticides onto Sediment

Samples of sediment from selected runoff events on fields 1 to 4 were characterized as to their particle size distribution and organic carbon content. Table 37 shows the composition of sediment in runoff water compared with the composition of surface soil from the 0- to 30-cm depth from the same fields. The sediment concentration of the water appeared to have little effect upon its particle size distribution or organic carbon content. The sediment has essentially the same characteristics in terms of particle size distribution and organic matter content as the soil from which the sediment was derived. This is in contrast to the enrichment of clay and organic matter in sediment compared with soils reported by Leonard et al. (*1979*) in runoff of watersheds from rainfed agriculture. They reported enrichment ratios ranging from 2 to 4, that is, the ratio of clay and organic matter in sediment to that in soil ranged between 2 and 4.

The enrichment of silt, clay, and organic matter in sediment is usually ascribed to preferential removal of the fine-grained fractions of the soil during erosion. The difference between enrichments reported by Leonard et al. (*1979*) in runoff from rainfed agriculture may in part be due to the raindrop effect in separating clay from coarser textured particles. The major reason for the difference, however, appears to be differences in amounts of coarse or medium sand in the soils from the two studies.

Figure 14. — Relationship between prometryn concentration in runoff water and concentrations in the surface soil (0-1 cm) for 12 runoff events.

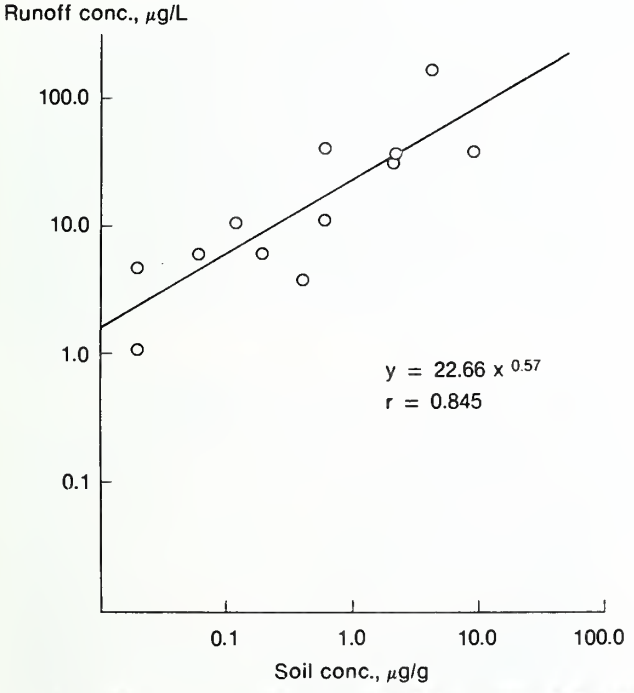
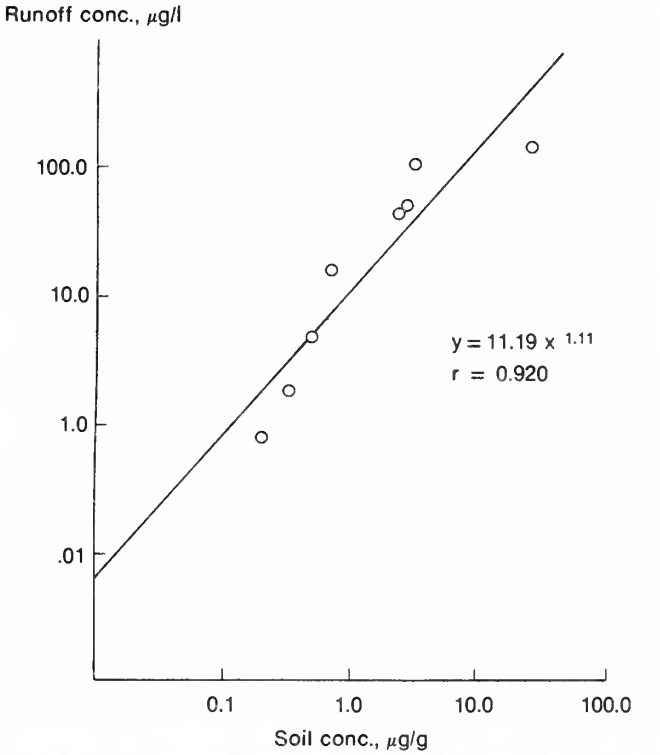


Figure 15. — Relationship between DCPA concentration in runoff water and concentration in the surface soil for eight runoff events.



The soils in the fields from Imperial Valley are very low in sand, and practically all of the sand fraction is very fine sand with only small amounts of fine sand and almost no medium and coarse sand. Even the silt fraction is predominately fine silt varying in size form 2 to 20 microns. In contrast, the average composition of the watershed soils used by Leonard et al. (*1979*) was 65.7 percent total sand with 72 percent of the total, either coarse or medium sand, and only 6.5 percent of the sand was very fine sand (Smith et al. *1978*). Evidently, the high enrichment ratios reported by Leonard et al. (*1979*) were due to the fact that only very small quantities of sand were transported off the watersheds in the runoff water, resulting in a much increased concentration of clay, silt, and organic matter in the remaining suspended sediment.

In Imperial Valley, almost the entire soil remained suspended in the runoff water until it passed over the outlet flume. Very little fractionation of the particle sizes occurred, resulting in little or no enrichment of clay and organic matter. In some cases, the clay and organic matter content of the sediment appeared to be somewhat higher than that in the soil, such as the runoff event in field 3 on March 26 to April 1, 1982 (table 37). An examination of the sampling and runoff record indicated that these samples were obtained while the portion of the field being irrigated was a long distance from the runoff measuring flume, allowing the coarser fraction of the sediment sufficient time to partially settle out in transit within the tailwater ditch between the furrow outlet and the flume.

Twenty-two water samples were separated into sediment and water phases to determine the partitioning of selected pesticides between sediment and water in runoff. Table 38 shows partitioning of three herbicides and three insecticides between sediment and water in runoff events from fields 1, 2, and 3. (Refer to table 37 for composition of the sediment in many of the samples analyzed for pesticides in sediment as reportd in table 38.) Except for fenvalerate, the amount of pesticide transported in sediment was small compared with that transported in water. Of the three herbicides, DCPA, prometryn, and trifluralin, 95, 100, and 65.6 percent, respectively, were transported in the water phase. Fenvalerate was almost completely transported on sediment (99.6 percent) whereas 85 percent of the chlorpyrifos and 94 percent of the endosulfan were transported in the water phase in the samples examined.

Figure 16. — Relationship between concentration of all herbicides in runoff water and concentration in the surface soil (0-1 cm).

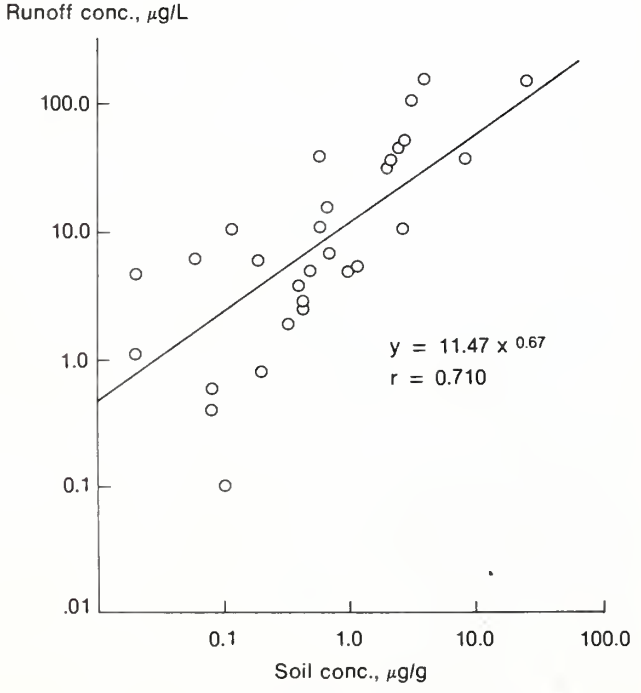


Figure 17. — Relationship between concentration of methomyl in runoff water and concentrations in the surface soil (0-1 cm) for nine runoff events.

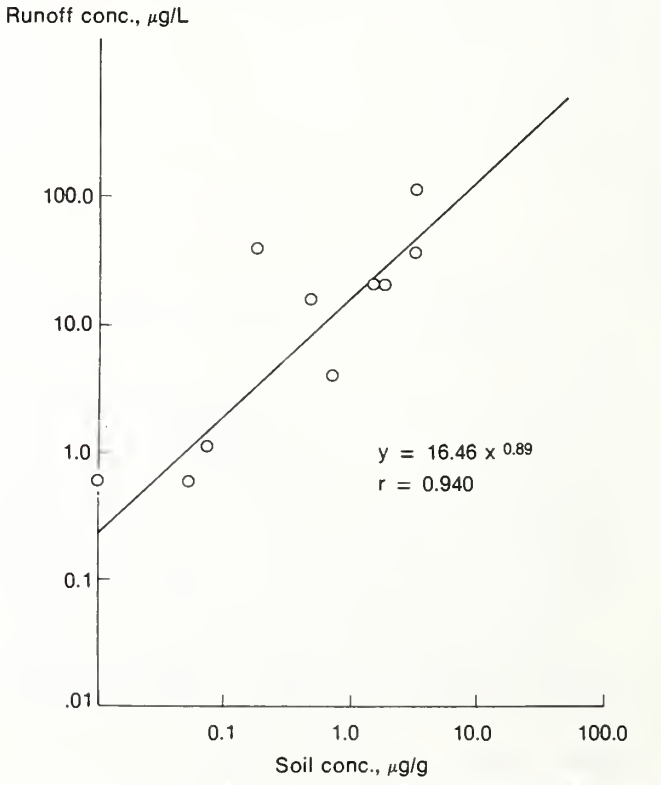
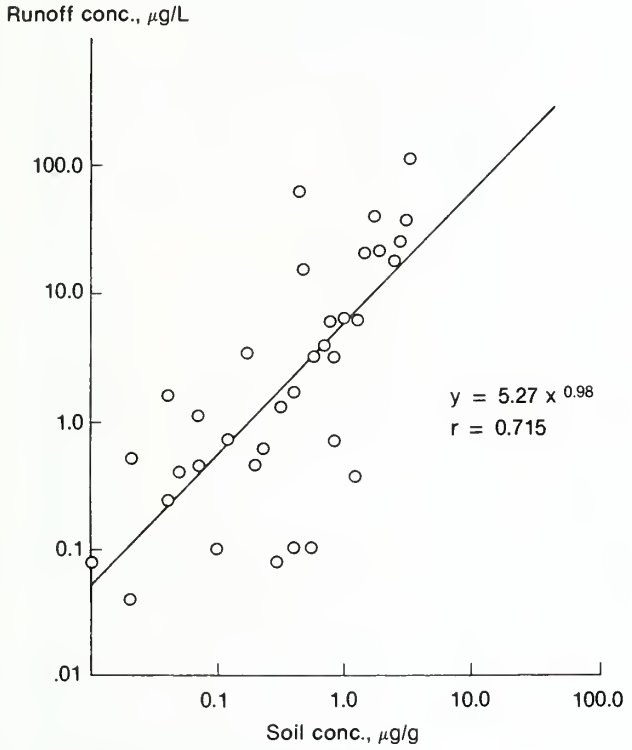


Figure 18. — Relationship between concentration in runoff water and concentrations in the surface soil (0-1 cm) for all insecticides (table 32).



The actual percentage of each pesticide transported in the sediment or water phase will depend upon the concentration of sediment in the runoff water. Partition coefficients, K_d, or the ratio of the pesticide concentration in sediment to concentration in water, were calculated to normalize the relationship for variable sediment levels. When nondetectable pesticide levels were observed in sediment or water, K_d values were calculated which reflected minimum detectable levels in the water or sediment phase.

K_d can be further extrapolated into K_{oc} values using the organic carbon content (oc) of the sediment, which ranged from 0.41 to 0.82 percent organic carbon ($K_{oc} = K_d \times 100/\text{percent oc}$). The K_{oc} values are somewhat erratic for some chemicals. They appear to be higher than expected from reported K_{oc} values using soils and the normal batch equilibrium method of measuring adsorption coefficients. The very low concentrations may be reasons for the high apparent K_d and K_{oc} values. We are in the process of determining distribution of pesticides between sediment and water under controlled conditions of adding known amounts of pesticides to water and suspended sediment, which should further clarify the factors affecting this distribution.

The proportion of trifluralin in sediment is somewhat higher than that reported by Leonard et al. (*1979*), but is more in agreement with that reported by Sheets et al. (*1972*) and G. H. Willis (personal communication). The calculated K_d for prometryn is obviously high because of the high minimum detectable level of prometryn in sediment compared with the concentration of prometryn in the runoff water sample. All the prometryn was found in the water phase. This would probably also be true for much higher prometryn concentrations, resulting in calculated K_d values much lower than those in table 38.

Table 33. — *Soil persistence as indicated by simple correlation (r) and linear regression for pesticide concentration in soil (C_S, µg/g) vs. time elapsed (t, days) since the last pesticide applications*

Pesticides	Log C_S vs. t[1]				$t_{½}$[2] and 95% confidence limits			C_S^O[3]
	n	*r*	*a*	*b*				
					----------Days----------			µg/g
Organophosphates								
Methidathion	4	-0.373	-0.017	-0.811	18	—	—	0.15
Ethyl parathion	8	-.771**	-.023	.183	13	10	20	1.5
Methyl parathion	8	-.908	-.039	-.209	7.8	6	12	.62
Pyrethroids								
Permethrin	8	-.064	-.009	-.212	33	—	—	.61
Fenvalerate	5	-.345	-.002	-.505	151	—	—	.31
Carbamate								
Methomyl	11	-.537	-.022	.019	14	9	29	1.0
Herbicides								
Prometryn	12	-.635*	-.018	.162	17	12	30	1.5
DCPA	8	-.854**	-.015	.984	20	16	28	9.6
Trifluralin	5	-.662	-.025	.361	12	7	34	2.3
Dinitramine	3	-.937*	-.015	.015	20	14	31	1.0
Organophosphates	25	-.586**	-.022	-.265	14	11	20	.54
Pyrethroids	13	-.380	-.003	-.318	100	—	—	.48
Organochlorines	3	.189	-.002	.049	151	—	—	1.1
Herbicides	30	-.548**	-.012	.229	25	19	35	1.7
All pesticides	82	-.376**	-.008	-.211	38	28	50	.62
Insecticides	52	-.379**	-.008	-.382	38	27	56	.41
Insecticides without pyrethroids	39	-.571**	-.023	-.109	13	11	17	.78

[1] Log $C_S = a\,t + b$.

[2] $t_{½} = \frac{-0.301}{a}$; 95 percent confidence limits based on standard error of estimate for a.

[3] C_S^O = antilog b.

* = significance at the 5 percent level.

** = significance at the 1 percent level.

Table 34. — *Soil persistence as indicated by simple correlation* (r) *and linear regression for log pesticide amounts* (A_S, *g/ha) and log percent of applied in soil vs. time elapsed* (t, *days) since the last pesticide application*

Pesticides	Log A_S vs. t[1]				Log percent applied vs. t[2]			
	n	*r*	*a*	*b*	*n*	*r*	*a*	*b*
Organophosphates								
Methidathion	4	−0.437	−0.019	1.283	4	−0.533	−0.027	0.546
Ethyl parathion	8	−.781**	−.024	2.232	8	−.540	−.021	.963
Methyl parathion	8	−.891**	−.039	1.814	8	−.734*	−.036	.842
Pyrethroids								
Permethrin	9	−.183	-.026	1.832	9	.216	.030	.948
Fenvalerate	5	−.458	−.003	1.528	5	−.789*	−.004	1.291
Carbamate								
Methomyl	11	−.558*	−.022	2.044	11	−.475	−.010	.678
Herbicides								
Prometryn	12	−.690**	−.020	2.217	12	−.779**	−.017	1.127
DCPA	8	−.858**	−.015	2.988	8	−.870**	−.013	1.318
Trifluralin	5	−.624	−.026	2.397	5	−.592	−.028	1.418
Dinitramine	3	−.990**	−.021	2.212	3	−.996**	−.017	1.060
Organophosphates	25	−.614**	−.023	1.744	25	−.520**	−.021	.635
Pyrethroids	14	−.445	−.004	1.686	14	−.479	−.003	1.134
Organochlorines	3	−.852	−.010	2.167	3	−.703	−.015	1.249
Herbicides	30	−.584**	−.014	2.272	30	−.764**	−.015	1.136
Insecticides	53	−.414**	−.009	1.627	53	−.339*	−.008	.660
Insecticides without pyrethroids	39	−.595**	−.024	1.904	39	−.500**	−.018	.708
All pesticides	83	−.411**	−.009	1.804	83	−.454**	−.009	.789

[1] Log $A_S = a\ t \times b$.
[2] Log percent $= a\ t + b$.
* = significance at the 5 percent level.
** = significance at the 1 percent level.

Table 35. — *Pesticide concentrations in irrigation runoff water samples as determined by 4 laboratories*[1] *[N.D. = not detectable]*

Runoff date	Field No.	Pesticide	Sample No.	Pesticide concentration, p/b			
				Lab. I	Lab. II	Lab. III	Lab. IV
7/28/79	3	Methidathion	1	7.1	L[2]	6.9	12.0
			2	0.8	L	0.3	1.0
			3	10.4	L	15.6	16.0
			4	18.0	L	18.0	3.0
		Fenvalerate	1	N.D. < 0.01	L		N.D. < 0.1
			2	N.D. < 0.01	L		N.D. < 0.1
			3	1.6	L		0.4
			4	0.2	L		0.3
9/22/79	5	Ethyl parathion	5	23.8	28.0	10.2	N.D. < 0.2[3]
			6	21.0	18.0	14.9	N.D. < 0.2
			7	12.3	14.0	13.4	N.D. < 0.2
			8	10.8	11.0	4.7	N.D. < 0.2
		Methyl parathion	5	8.0	11.0	4.7	0.5
			6	5.8	7.0	6.2	N.D. < 0.2
			7	3.5	5.3	5.8	N.D. < 0.2
			8	2.8	3.9	4.7	N.D. < 0.2
		Diazinon	5	N.D. < 0.03	.01		
			6	N.D. < 0.03	.02		
			7	N.D. < 0.03	.01		
			8	N.D. < 0.03	< .01		
		Methomyl	5	62			76
			6	62			56
			7	54			54
			8	16			71
8/24/80	2	Methidathion	9	56.3	L		64.0
			10	12.3	7.8		17.5
			11	10.1	7.0		8.3
			12	5.8	L		8.3
		Fenvalerate	9	—			200
			10	133			90
			11	29			34
			12	—			34
		Prometryn	9	4.3	L		
			10	3.4	1.7		
			11	4.1	1.5		
			12	2.7	L		
		Trifluralin	9	1.2	L		
			10	0.77	1.9		
			11	0.71	2.1		
			12	0.75	L		
9/2/80	6	Ethyl parathion	13	2.5	L		3.6
			14	2.7	2.8		3.6
			15	2.8	3.0		3.4
			16	1.6	L		0.8
		Methyl parathion	13	N.D. < 0.03	L		.1
			14	N.D. < 0.03	.2		.03
			15	N.D. < 0.03	.2		.2
			16	N.D. < 0.03	L		N.D. < 0.01

Table 35. — *Pesticide concentrations in irrigation runoff water samples as determined by 4 laboratories[1] [N.D. = not detectable)*
(continued)

Runoff date	Field No.	Pesticide	Sample No.	Pesticide concentration, p/b			
				Lab. I	Lab. II	Lab. III	Lab. IV
		Mevinphos	13	N.D. < 0.1	L		.1
			14	N.D. < 0.1	.12		.1
			15	N.D. < 0.1	.2		.1
			16	N.D. < 0.1	L		N.D. < 0.1
9/14/80	2	Methidathion	17	2.2	2.0	1.4[4]	1.3
			18	2.1	2.5	0.7	1.2
			19	1.9	2.1	1.3	1.7
			20	1.8	2.0	1.3	1.4
		Fenvalerate	17	—		N.D. < 0.5	N.D. < 1.0
			18	.14		N.D. < 0.5	N.D. < 1.0
			19	—		N.D. < 0.5	N.D. < 1.0
			20	.38		N.D. < 0.5	N.D. < 1.0
		Prometryn	17	N.D. < 0.8	.6	1.0	
			18	N.D. < 0.8	.3	1.0	
			19	N.D. < 0.8	.6	1.0	
			20	N.D. < 0.8	.5	1.0	
		Trifluralin	17	.45	.6	.49	
			18	.32	.8	.60	
			19	.33	.7	.49	
			20	.33	.8	.52	

[1]Samples were analyzed by cooperating laboratories from U.S. Geological Survey, Denver, Colo.; Food and Drug Administration, Los Angeles, Calif.; EPA, Bay St. Louis, Miss.; and ARS, Riverside, Calif. (lab. I).
[2]Samples lost during transit.
[3]Samples 5-8 were extracted by lab IV after an extended storage period, which probably resulted in degradation of ethyl and methyl parathion in the high pH waters.
[4]Samples 17-20 stored at 4°C for 12 months by lab III prior to extraction and analysis.

Table 36. — *Comparison of pesticide losses in runoff (R.O.) calculated using the full integration method with values calculated using average concentrations during peak flows only*

Field No.	Runoff date	Pesticide amounts in runoff						
		Chemical	Integration method	Peak flow averaging[1]		All peak average × total R.O. vol.[2]		1st peak average × total R.O. vol.[3]	
			G/ha	G/ha	Percent difference	G/ha	Percent difference	G/ha	Percent difference
4	10/7-9/79 (fig. 6)[4]	Methomyl	6.2	6.1	−2	6.5	+5	8.8	+ 42
		Ethyl parathion	3.1	2.6	−16	2.6	−16	2.6	− 16
		Methyl parathion	1.2	1.0	−17	1.0	−17	1.1	− 8
5	9/22-24/79 (fig. 4)	Cycloate	.82	.86	+5	.84	+2	.81	− 1
		Ethyl parathion	8.5	7.3	−14	7.2	−15		
		Methyl parathion	2.1	1.9	−10	1.8	−14		
5	11/7-9/79 (fig. 7)	Diazinon	.17	.17	0	.19	+12	.27	+ 59
1	7/24-26/79 (fig. 1)	Prometryn	72	38	−47	53	−26	45	− 38
1	8/22-24/79	Prometryn	9.3	9.7	+4	10.7	+15	13.4	+ 44
		Chlorpyrifos	.18	.16	−11	.16	−11	.15	− 20
1	9/4-7/79	Prometryn	7.9	7.5	−5	13	+64	24	+204
1	10/2-4/79 (fig. 3)	Prometryn	12.8	12.9	+1	23	+79	42	+226

[1]Amounts = $C_1V_1 + C_2V_2 + \text{---} C_nV_n$, where C_1, C_2, C_n and V_1, V_2, V_n are average concentrations and runoff volumes for flow peaks 1, 2, and n, respectively.

[2]Amount = $\left(\frac{C_1 + C_2 + \text{---} C_n}{n}\right) V_t$. where V_t is total runoff volume.

[3]Amounts = $(C_1)\ V_t$.

[4]Figure number indicates the figure showing the runoff event hydrograph.

Table 37. — *Composition of sediment in runoff water compared with surface soil from 4 field sites*

Field No.	Sample No.	Runoff dates	Sediment concentration	Particle size distribution			Organic carbon content
				Sand 50μ	Silt 2-50μ	Clay <2μ	
			G/L	*Percent*	*Percent*	*Percent*	*Percent*
1	513	8/4-7/81	0.94	23.4	28.2	48.4	0.55
	514	8/4-7/81	1.05	24.2	28.3	47.6	.82
	515	8/4-7/81	1.19	13.4	36.8	49.9	.77
	Mean	—	1.06	20.3	31.1	48.6	.71
	Soil, 0-30 cm.		—	20	34	46	.54
2	Mean[1]	11/24-12/29/81	.267	31.2	31.4	37.4	.62
	Soil, 0-30 cm.		—	13	38	49	.56
3	313	8/25-26/81	.202	2.4	75.3	22.3	.71
	316	9/3-5/81	1.31	26.5	41.1	32.5	.41
	322	9/3-5/81	.752	17.4	48.0	34.6	.45
	337	1/14-15/82	.152	31.8	34.2	34.0	—
	339	1/14-15/82	.555	41.6	27.8	30.6	—
	343	3/26-4/1/82	2.485	13.9	26.9	59.2	.57
	346	3/26-4/1/82	1.808	9.3	31.4	59.2	.52
	Mean	—	1.037	20.4	40.7	38.9	.53
	Soil, 0-30 cm.		—	25	47	28	.38
4	219	10/28-30/79	4.090	1.3	45.0	53.7	.46
	220	10/28-30/79	4.235	1.5	48.0	50.5	.40
	225	10/28-30/79	2.898	1.6	46.1	52.2	.38
	228	10/28-30/79	3.238	3.3	50.1	46.6	.40
	Mean	—	3.615	1.9	47.3	50.8	.41
	Soil, 0-30 cm.		—	5	46	49	.74

[1]Data from a composite sample of 4 runoff samples (Nos. 106, 116, 119, 125) varying in sediment content between 0.105 and 0.374 g/L.

Table 38. — *Partitioning of selected pesticides between sediment and water in runoff from furrow irrigated fields*

Pesticides	Field No.	Sample No.	Runoff dates	Sediment conc.	Pesticides in runoff					K_d[1]	K_{oc}[6] ×10⁻³
					In sediment	In water	Total	Percent in sediment	Percent in water		
				G/L	µg/g	µg/L	µg/L				
DCPA	1	442a	4/29/81	1.86	0.46	0.86	21.8	22.7	4.0	96	21	2.9
	1	442b	4/29/81	1.86	.68	1.26	21.2	22.5	5.6	94.4	32	4.5
	1	513	8/5/81	1.14	.02	.02	7.54	7.56	.3	99.7	2.7	.4
	3	313	8/26/81	.18	.23	.04	2.18	2.22	1.8	98.2	106	14.9
	3	316	9/3/81	2.20	.13	.28	2.20	2.48	11.3	88.7	59	8.3
	3	332	9/5/81	.16	N.D.	—	.57	.57	—	100	[2]<18	
Mean									4.6	95.4	40	6.0
Prometryn	1	513	8/5/81	1.14	N.D.	—	1.99	1.99	—	100	[3]<402	—
		514	8/5/81	1.25	N.D.	—	2.70	2.70	—	100	[3]<296	—
Mean									0	100	<350	—
Trifluralin	2	16	7/12/80	5.07	1.10	5.56	5.87	11.43	48.6	51.4	187	33.4
	3	343	3/26/82	1.53	.194	.297	.40	.70	42.7	57.3	486	87.0
	3	346	3/26/82	.89	.103	.092	.69	.78	11.8	88.2	150	27.0
Mean									34.4	65.6	274	49.0
Chlorpyrifos	1	513	8/5/81	1.14	9.6	10.9	95.0	106	10.3	89.7	101	18.4
	1	514	8/5/81	1.25	67.8	85.0	218	303	28.1	71.9	312	38.0
	3	316	9/3/81	2.20	.79	1.74	4.86	6.60	26.4	73.6	163	39.8
	3	322	9/4/81	.76	.67	.51	4.74	5.25	9.7	90.3	141	31.3
	3	332	9/5/81	.16	N.D.	—	1.35	1.35	—	100	[4]<74	—
Mean									15	85	179	31.3
Endosulfan	2	106	12/9/81	.42	1.20	.50	4.32	4.82	10.4	89.6	278	49.6
	2	116	12/9/81	.21	.48	.10	2.08	2.18	4.6	95.4	231	41.2
	2	119	12/9/81	.45	.22	.10	1.84	1.94	5.2	94.8	120	21.4
	2	125	12/9/81	.41	3.20	1.32	16.02	17.34	7.6	92.4	200	35.7
	2	132	12/9/81	.06	2.95	.18	7.13	7.31	2.5	97.5	414	73.9
Mean									6.1	93.9	249	44.5
Fenvalerate	1	513	8/5/81	1.14	48.7	55.5	.99	56.5	98.2	1.8	4.92×10^3	890
	1	514	8/5/81	1.25	127	159	1.75	161	98.9	1.1	7.26×10^3	890
	2	51a	8/24/80	3.08	133	408	N.D.	408	100	—	[5]$>33 \times 10^5$	—
	2	51b	8/24/80	3.13	125	392	N.D.	392	100	—	[5]$>31 \times 10^5$	—
	2	52a	8/24/81	3.86	37	143	N.D.	143	100	—	[5]9.3×10^5	—
	2	52b	8/24/80	3.14	45	142	N.D.	142	100	—	[5]$>11 \times 10^5$	—
	2	53a	8/24/80	2.03	13.8	28.0	N.D.	28.0	100	—	[5]$>3.5 \times 10^5$	—
	2	53b	8/24/80	2.21	14.3	31.7	N.D.	31.7	100	—	[5]$>3.6 \times 10^5$	—
Mean									99.6	.4	$>11.4 \times 10^5$	890

[1] K_d = (Conc. in sediment, µg/kg)/(conc. in water, ug/L).
[2] K_d value based on a minimum detectable level (MDL) of 0.01 µg/kg DCPA in sediment.
[3] K_d values based on MDL = 0.80 µg/kg prometryn in sediment.
[4] K_d value based on MDL = 0.10 µg/kg chlorpyrifos in sediment.
[5] K_d value based on MDL = 0.04 ug/L fenvalerate in water.
[6] $K_{oc} = \frac{K_d \times 100}{\%\ \text{organic carbon}}$

Summary and Conclusions

Concentrations and amounts of pesticides in irrigation runoff water from large fields in Imperial Valley, California, varied widely depending upon the characteristics of the pesticides, their methods and rates of application, the time elapsed between application and the first irrigation, irrigation efficiency, and soil and crop management practices. The percentages of the applied pesticides lost in runoff water were generally very low with the exception of EPTC applied directly in irrigation water, insecticides applied by air while irrigation water was on the field, and some herbicide applications applied at midseason as a directed spray to growing cotton.

Higher runoff rates occurred from soil applied herbicides than from aerially applied insecticides, and the herbicides persisted longer than did the insecticides. Most of the soil-applied herbicides were lost to the extent of 1 to 2 percent of the application, whereas insecticides were generally lost in amounts less than 1 percent of the application. Some of the organophosphate insecticides and the pryrethroids appeared in runoff water in extremely low amounts, generally equivalent to much less than 0.1 percent of the amounts applied. Most of the losses occurred during the first irrigation after application and runoff losses can be appreciably decreased by extending the time between pesticide application and irrigation. The water runoff hydrograph-concentration relationship indicated changes in concentration of most pesticides during an irrigation event generally followed an inverse relationship with runoff water volume.

Aerial applications of insecticides, while irrigation water was on the field, markedly increased the concentration of the insecticides in the runoff water for several hours after the application. This practice should definitely be avoided to prevent slug concentrations of pesticides in irrigation return flows from surface irrigation runoff waters. Runoff loss of EPTC, or any other pesticide applied in the irrigation water, is directly related to the volume of irrigation water lost as runoff during the irrigation application; consequently, the quantities lost in runoff can be greatly decreased by increasing irrigation efficiency by minimizing runoff during the application irrigation. With the exception of the pyrethroids, the time elapsed since the last pesticide application was directly correlated with $\log_{10}$ of the pesticide concentration in runoff. This indicates that the pesticide concentration in runoff water decreased at a first-order rate with time. This relationship will be useful in models developed to estimate pesticide concentrations to be expected in runoff water at various times following pesticide applications. Except for the pyrethroids, the amount of pesticides transported in sediment was small compared with that transported in water. This was to be expected because most of the pesticides in the runoff water were associated with the water phase rather than the sediment phase.

Correlations between soil concentrations and concentrations of pesticide in runoff water indicate that the concentrations and amounts of pesticides in the 0- to 1-cm depth of soil are good indicators of the concentrations and amounts to be expected in runoff water under furrow irrigation systems, such as those used in the Imperial Valley. Highly significant correlations were observed for most of the pesticides and pesticide groups with the exception of the pyrethroids.

The limited data available from a laboratory comparison study indicated good agreement among the various laboratories for analysis of most of the pesticides considering the extremely low levels in the range of 10 p/b or less in sediment-laden runoff water. A comparison of pesticide losses, calculated using only average concentrations during peak flows with calculations using the full integration method for several irrigation runoff events, indicates that the total pesticide runoff can be quite accurately estimated using only pesticide concentrations from the peak flows. This means that sampling efficiency could be improved by decreasing the numbers of samples taken to estimate total pesticide runoff during an irrigation event under many conditions.

Tile drain effluents contribute insignificant amounts of presently used pesticides to irrigation return flows compared with the amounts from irrigation runoff waters. Even the amounts of pesticides in runoff waters represent a very small percentage of that applied. These findings are consistent with the very low pesticide concentrations observed by Eccles *(1979)* in the main drainage channels carrying irrigation return flows to the Salton Sea.

The results indicate that amounts of pesticide lost in runoff water can be considerably lessened by (1) choice of pesticide and its method of application, (2) extending the waiting period between application and irrigation, and (3) increasing irrigation efficiency through preventing excessive loss of irrigation water in runoff. The runoff of pesticides applied directly in irrigation water can be greatly decreased by preventing runoff losses of irrigation water during application.

The results should be generally applicable to other irrigated areas using similar irrigation systems and methods of applying pesticides. The detailed data on pesticides in irrigation runoff water as influenced by pesticide characteristics, time, methods of pesticide application, and irrigation practices provide a data base that can assist in developing and testing an operational irrigation-pesticide model to extrapolate these findings to other areas and conditions. This would be extremely helpful in evaluating alternative pesticide application or irrigation practices to minimize movement of organic chemicals into water supplies under various field conditions.

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Appendix

Table 1. — *Pesticides in soil, 0-1 cm depth, and in surface runoff from the subsequent irrigation event (field 1, cotton, 1979, 1980)*

Pesticide application		Soil sampling					Pesticides in soil, 0-1 cm					Pesticides in runoff		
					Since last pest. application		Amount							
Chemical	Total applied	Date sampled	No. of samples	Cores/ sample	No. of days	No. of irriga-tions	Min-imum	Max-imum	Mean	Coeff. of var.	Conc. (mean)	Conc. (mean)	Amount	Percent of amount in soil
1979	*Kg/ha*						------	*G/ha*	------	*Percent*	*P/m*	*P/b*	*G/ha*	*Percent*
Prometryn	2.24	6/12/79	11	60	56	2	37	128	58	45	0.6	11.2	5.6	10
	2.24	7/5/79	10	120	79	3	10	43	23	49	.4	3.9	4.1	18
	3.14	8/2/79	10	40	14	1	30	180	80	68	.6	40	9.5	12
Dinitramine	.75	6/12/79	11	60	56	2	5	11	8	31	.08	.6	.3	3.8
	.75	7/5/79	10	120	79	3	1	10	4	76	.08	.4	.4	.1
	1.31	8/2/79	10	40	14	1	20	140	90	41	.7	7.0	1.7	1.9
Chlorpyrifos	.96	8/2/79	10	40	1	0	120	170	150	15	1.2	N.D.[1]	—	—
Permethrin	.35	8/2/79	10	40	1	0	31	44	36	11	.3	.08	.02	.06
1980														
Prometryn	.3	6/23/80	9	60	70	2	.8	3.0	1.7	36	.02	4.8	1.4	82
	1.6	8/4/80	10	60	3	0	590	900	780	18	8.7	38	7.5	1.0
DCPA	3.4	6/23/80	9	60	70	2	29	94	67	35	.7	16	4.5	6.7
	7.6	8/4/80	10	60	3	0	860	3080	2400	33	28	153	30.5	1.3
Methomyl	.4	6/23/80	9	60	37	1	2.9	10	6.4	42	.07	1.1	.33	5.2
	.4	8/4/80	10	60	79	3	2.9	7.0	5.1	29	.05	N.D.	—	—
Fenvalerate	.11	8/4/80	10	60	1	0	12	63	35	67	.4	.10	.02	.06

[1]N.D. = not detectable.

Table 2. — *Pesticides in soil, 0-1 cm depth, and in surface runoff from the subsequent irrigation event (field 1, cotton, 1981)*

Pesticide application		Soil sampling					Pesticides in soil, 0-1 cm					Pesticides in runoff		
					Since last pest. application		Amount							
Chemical	Total applied	Date sampled 1981	No. of samples	Cores/ sample	No. of days	No. of irriga-tions	Min-imum	Max-imum	Mean	Coeff. of var.	Conc. (mean)	Conc. (mean)	Amount	Percent of amount in soil
	Kg/ha						------ *G/ha* ------			*Percent*	*P/m*	*P/b*	*G/ha*	*Percent*
Prometryn	0.3	3/28/81	10	60	2	0	N.D.[1]	21	14	31	0.12	10.9	5.8	41
	.3	4/28/81	10	60	33	1	3.8	7.3	5.5	24	.06	6.3	1.9	35
	.3	6/10/81	4	60	76	3	.85	2.0	1.7	32	.02	1.1	.4	24
	1.6	6/26/81	10	60	1	0	116	318	211	37	2.1	33	13.3	6.3
	1.6	7/16/81	2	150	20	2	11	27	19	60	.19	6.2	1.12	5.8
DCPA	3.4	3/28/81	10	60	2	0	127	544	294	46	2.53	46.8	24.8	8.5
	3.4	4/28/81	10	60	33	1	219	351	262	18.7	2.8	52.3	15.7	6.1
	3.4	6/10/81	4	60	76	3	15	65	45.8	52	.5	5.0	1.9	4.1
	3.4	6/26/81	10	60	93	4	20	49	32.1	24	.33	1.9	.74	2.2
	3.4	7/16/81	2	150	113	6	15	20	17.7	19	.2	.8	.14	.6
Trifluralin	1.1	6/26/81	10	60	1	0	47	163	100	45	1.0	5.0	2.0	2.0
	1.1	7/16/81	2	150	20	2	35	45	40.3	18	.43	2.8	.5	1.3
Chlorpyrifos	.28	7/16/81	2	150	1	0	51	61	56	13	.6	3.3	.59	1.1
Permethrin	.20	7/16/81	2	150	1	0	77	82	80	4	.85	.7	.13	.16

[1]N.D. = not detectable.

Table 3. — *Pesticides in soil, 0-1 cm depth, and in surface runoff from the subsequent irrigation event (field 2, cotton, 1980; lettuce, 1981)*

Pesticide application		Soil sampling					Pesticides in soil, 0-1 cm					Pesticides in runoff		
					Since last pest. application		Amount							
Chemical	Total applied	Date sampled	No. of samples	Cores/ sample	No. of days	No. of irriga-tions	Min-imum	Max-imum	Mean	Coeff. of var.	Conc. (mean)	Conc. (mean)	Amount	Percent of amount in soil
Cotton, 1980	*Kg/ha*						------ *G/ha* ------			*Percent*	*P/m*	*P/b*	*G/ha*	*Percent*
Prometryn	1.3	7/11/80	10	30	4	0	160	960	480	47	4.2	163	9.3	1.9
	1.3	7/25/80	10	30	18	1	110	471	250	47	2.2	37	1.6	.6
Trifluralin	.96	7/11/80	10	30	4	0	200	480	330	24	2.8	10.7	.61	.2
	.96	7/25/80	10	30	18	1	40	340	140	79	1.2	5.6	.24	.1
Lettuce, 1981														
Ethyl parathion	.83	11/24/81	6	60	28	0	31	41	37	12	.32	1.3	.13	.36
	.83	12/8/81	4	60	42	2	17	24	20.9	14	.23	.6	.05	.24
Methyl parathion	.42	11/24/81	6	60	28	0	5.2	6.6	6.1	8.8	.56	.1	.01	
	.42	12/8/81	4	60	42	2	1.4	2.5	1.9	24	.02	.04	.003	
Methomyl	1.43	11/24/81	6	60	10	0	139	237	196	19	1.8	41	4.0	2.0
	2.55	12/8/81	4	60	6	0	118	501	321	49	3.4	119	10	3.1
Endosulfan	.84	11/24/81	6	60	10	0	51	163	113	38	1.0	6.2	.61	.54
	.84	12/8/81	4	60	24	0	69	88	78	12	.85	3.2	.27	.35

Table 4. — *Pesticides in soil, 0-1 cm depth, and in surface runoff from the subsequent irrigation event (field 3, cotton 1978, 1979, 1981; lettuce, 1980)*

Pesticide application		Soil sampling					Pesticides in soil, 0-1 cm					Pesticides in runoff		
					Since last pest. application		Amount							
Chemical	Total applied	Date sampled	No. of samples	Cores/ sample	No. of days	No. of irriga-tions	Min-imum	Max-imum	Mean	Coeff. of var.	Conc. (mean)	Conc. (mean)	Amount	Percent of amount in soil
Cotton, 1978	*Kg/ha*						------*G/ha*------			*Percent*	*P/m*	*P/b*	*G/ha*	*Percent*
Methidathion	1.12	9/1/78	5	10	45	3	1.3	17	8.8	85	0.1	0.1	0.02	0.2
Permethrin	.34	9/1/78	5	10	8	0	17	154	66	86	.5	N.D.	—	—
Cotton, 1979														
Methidathion	.54	7/27/79	10	30	6	0	7.4	92	49	52	.46	64	20.4	42
	1.02	8/27/79	10	20	29	1	1.2	5.0	2.8	49	.02	.5	.08	2.9
Fenvalerate	.08	7/27/79	10	30	6	0	.8	8.1	4.5	47	.04	1.6	.5	11
	.35	8/27/79	10	20	19	0	51	86	67	22	.53	N.D.	—	—
Permethrin	.4	8/27/79	10	20	6	0	8.1	43	22	51	.17	3.4	.54	2.5
Methomyl	.2	8/27/79	10	20	19	0	N.D.[1]	2.9	1.4	54	.01	N.D.	—	—
Lettuce, 1980														
Ethyl parathion	4.2	12/11/80	3	60	24	0	39	57	49	18	.41	1.7	.37	.8
Methyl parathion	2.1	12/11/80	3	60	24	0	5	7	6	16	.05	.4	.09	1.6
Methomyl	3.16	12/11/80	3	60	12	0	30	130	83	60	.7	4.0	.9	1.0
Cotton, 1981														
DCPA	3.6	6/4/81	10	60	69	2	179	600	400	33	3.3	111	15.5	4.0

[1]N.D. = not detectable.

Table 5. — *Pesticides in soil, 0-1 cm depth, and in surface runoff from the subsequent irrigation event (field 4, sugarbeets, 1978, 1979; field 5, sugarbeets, 1979, 1980)*

Pesticide application		Soil sampling					Pesticides in soil, 0-1 cm					Pesticides in runoff		
					Since last pest. application		Amount							
Chemical	Total applied	Date sampled	No. of samples	Cores/ sample	No. of days	No. of irriga-tions	Min-imum	Max-imum	Mean	Coeff. of var.	Conc. (mean)	Conc. (mean)	Amount	Percent of amount in soil
	Kg/ha						------*G/ha*------			*Percent*	*P/m*	*P/b*	*G/ha*	*Percent*
Field 4, sugarbeets, 1978-79														
Ethyl parathion	0.55	9/19/78	10	20	5	0	47	765	277	87	2.6	18	5.6	2.0
	1.11	11/16/78	40	120	50	0	9	31	20	24	.2	.45	.07	.4
Methyl parathion	.28	9/19/78	10	20	5	0	3.1	273	86	111	.8	6.1	1.7	2.0
	.56	11/16/78	40	120	50	0	.6	2.0	1.2	28	.01	.08	.01	.8
Methomyl	3.49	11/16/78	40	120	24	0	98	400	174	30	1.8	21	3.2	1.8
Field 5, sugarbeets, 1979-80														
Ethyl parathion	2.5	9/21/79	10	30	0	0	80	550	330	47	2.9	26.1	8.5	2.6
Methyl parathion	1.26	9/21/79	10	30	0	0	40	250	150	46	1.3	6.4	2.1	1.4
Methomyl	3.16	9/21/79	10	30	0	0	111	809	363	54	3.2	38	12	3.4
	5.13	10/12/79	10	60	3	0	68	235	142	42	1.5	21	3.4	2.4
	5.82	11/6/79	10	60	19	0	3.9	82	44	73	.48	15.7	3.7	8.4
Diazinon	.48	11/6/79	10	60	19	0	6.0	16	11	28	.12	.72	.17	1.6
Cycloate	2.9	9/21/79	10	30	27	0	27	75	48	29	.43	2.5	.9	1.9
	2.9	10/12/79	10	60	48	1	4.4	20	13	38	.14	N.D.[1]	—	—

[1]N.D. = not detectable.

Table 6. — *Pesticides in soil, 0-1 cm depth, and in surface runoff from the subsequent irrigation event (field 8, lettuce 1979; field 3, melons, 1982; field 10, cotton, 1979, 1981)*

Pesticide application		Soil sampling					Pesticides in soil, 0-1 cm					Pesticides in runoff		
					Since last pest. application		Amount							
Chemical	Total applied	Date sampled	No. of samples	Cores/ sample	No. of days	No. of irriga-tions	Min-imum	Max-imum	Mean	Coeff. of var.	Conc. (mean)	Conc. (mean)	Amount	Percent of amount in soil
	Kg/ha						------*G/ha*------			*Percent*	*P/m*	*P/b*	*G/ha*	*Percent*
Field 8, lettuce, 1979														
Diazinon	0.77	1/31/79	15	60	78	1	4	15	6	21	0.07	0.45	0.024	0.3
Malathion	1.6	1/31/79	15	60	20	0	1.6	8.3	3.4	53	.04	.24	.013	.29
Ethylan	1.6	1/31/79	15	60	20	0	74	139	104	43	1.25	.37	.02	.02
Field 3, melons, 1982														
Trifluralin	.83	3/26/82	10	30	4	0	195	429	300	25	2.8	1.25	.81	.27
Field 10, cotton, 1979														
Permethrin	.22	7/17/79	10	20	2	0	14	60	33	49	.26	N.D.[1]	—	—
Field 10, cotton, 1981														
Permethrin	.57	7/27/81	2	35	3	0	173	317	245	42	2.1	N.D.	—	—
	1.17	8/20/81	2	30	5	0	126	147	137	11	1.6	N.D.	—	—

[1]N.D. = not detectable.

Table 7. — *Sediment in irrigation runoff water from furrow irrigated fields in Imperial Valley, Calif.*

Runoff dates	Irrigation runoff: Water applied	Irrigation runoff: Runoff volume	Sediment in runoff: Mean concentration[1]	Sediment in runoff: Amount lost
	L/ha × 10⁵ (cm)	*L/ha × 10⁵ (cm)*	*G/L*	*Kg/ha*
Field 1, 1979 — cotton, 28 ha				
4/22-27/79	26	13.1	0.72	940
5/6-10/79	16.3	5.7	.51	290
6/12-14/79	16.2	5.0	.66	330
7/6-11/79	19	10.4	1.09	1130
7/24-26/79	14.2	4.0	2.08	830
8/6-9/79	15.3	[2](2.4)	.96	230
8/22-24/79	13.7	3.6	.69	250
9/4-7/79	15.3	2.2	.29	64
9/19-21/79	15.2	(4.6)	.65	300
10/2-4/79	15.2	4.0	.80	320
Totals	**166.4**	**55.0**	**.85**	**4684**
Field 1, 1980 — cotton, 28 ha				
4/14-18/80	17.7	(4.8)	.21	170
5/27-29/80	19.0	3.1	1.00	360
6/23-27/80	12.5	2.9	.76	180
7/18-21/80	21.1	3.2	1.03	470
8/5-8/80	17.1	(2.0)	1.45	270
8/18-21/80	15.2	3.4	1.71	770
9/2-4/80	12.1	1.3	1.15	290
9/16-18/80	12.2	(2.2)	.86	250
9/30-10/81	12.2	2.7	1.37	620
2/20-24/81	27.0	4.3	.63	170
Totals	**166.1**	**29.9**	**1.18**	**3550**
Field 1, 1981 — cotton, 28 ha				
3/28-4/1/81	18.3	5.3	.55	290
4/28-30/81	12.5	3.0	1.07	320
5/21-23/81	12.2	(3.0)	1.43	430
6/11-13/81	12.9	3.8	1.00	380
6/26-28/81	12.2	4.0	.19	77
7/7-9/81	10.8	.9	1.55	140
7/16-18/81	10.7	1.8	.67	120
7/27-28/81	10.4	1.8	.43	78
8/4-7/81	9.7	1.8	.41	74
8/18-19/81	4.7	1.8	.19	35
8/31-9/3/81	11.0	.7	1.41	99
9/14-17/81	10.0	2.6	.69	180
Totals	**135.4**	**30.5**	**.73**	**2223**

Table 7. — *Sediment in irrigation runoff water from furrow irrigated fields in Imperial Valley, Calif. (continued)*

Runoff dates	Irrigation runoff: Water applied	Irrigation runoff: Runoff volume	Sediment in runoff: Mean concentration[1]	Sediment in runoff: Amount lost
	L/ha × 10⁵ (cm)	*L/ha × 10⁵ (cm)*	*G/L*	*Kg/ha*
Field 2, 1980 — cotton, 28 ha				
7/12-13/80	14.3	(.6)	1.07	64
7/25-27/80	11.6	.4	1.17	47
8/24-26/80	13.4	(3.1)	.55	170
9/13-16/80	24.3	2.4	.54	130
4/6-8/81	[3]10.9	1.3	.85	110
4/22/81	6.5	(.8)	.55	44
Totals	**81**	**8.6**	**.66**	**565**
Field 2, 1981-82 — lettuce, 28 ha				
11/24-26/81	10.5	1.0	.26	26
12/8-9/81	3.6	.8	.29	23
12/26-29/81	8.4	1.1	.37	41
Totals	**22.5**	**2.9**	**.31**	**90**
Field 3, 1978 — cotton, 28 ha				
7/9-10/78	7.8	(1.6)	.75	120
7/30-8/1/78	16.0	2.2	1.09	240
8/16-17/78	12.5	1.0	.90	90
9/1-2/78	11.5	2.0	.55	110
9/12-13/78	10.8	1.7	.22	38
Totals	**58.6**	**8.5**	**.70**	**598**
Field 3, 1979 — cotton, 14 ha				
7/28-29/79	17.6	(3.2)	.24	78
8/29-31/79	16.9	1.6	.17	27
Totals	**34.5**	**4.8**	**.21**	**105**
Field 3, 1980-81 — lettuce, 28 ha				
10/22-24/80	13.4	2.9	.41	120
11/14-15/80	10.4	3.5	.63	220
12/10-12/80	11.4	(2.2)	2.73	600
12/30-31	[4]1.9	[5].01	.10	0.1
2/21/81	[6]18.0	3.3	.36	120
3/29/81	[7]21.0	5.5	.20	110
4/16/81	3.7	.5	.86	43
Totals	**79.8**	**17.9**	**.68**	**1210**
Field 3, 1981 — cotton, 28 ha				
3/29-4/3/81	21	(5.5)	0.20	110
4/16-17/81	3.7	(.5)	.86	43
6/10-11/81	13.4	1.4	1.14	160
6/24-25/81	13.5	2.2	1.27	280
7/9-10/81	12.2	(2.5)	1.28	320
7/21-22/81	12.2	(3.3)	.67	220
7/31-8/1/81	12.1	(2.0)	.45	91
8/11-12/81	5.0	(0.5)	.40	20
8/25-26/81	13.0	(2.0)	.20	40
9/3-5/81	10.6	(1.3)	.58	76
9/17-18/81	13.1	(2.1)	.25	52
Totals	**129.8**	**23.3**	**.61**	**1412**

Table 7. — *Sediment in irrigation runoff water from furrow irrigated fields in Imperial Valley, Calif. (continued)*

Runoff dates	Irrigation runoff: Water applied	Irrigation runoff: Runoff volume	Sediment in runoff: Mean concentration[1]	Sediment in runoff: Amount lost
	L/ha × 10⁵ (cm)	*L/ha × 10⁵ (cm)*	*G/L*	*Kg/ha*
Field 4, 1978-79 — sugarbeets, 54 ha				
9/19-23/78	12.8	(2.8)	.39	110
11/17-21/78	9.3	1.5	1.07	160
1/5-7/79	8.2	2.9	.26	75
2/9-11/79	10.0	3.4	.29	100
Totals	**40.3**	**10.6**	**.42**	**445**
Field 4, 1979-80 — sugarbeets, 54 ha				
9/14-19/79	11.6	5.0	.54	270
10/7-9/79	9.6	2.4	1.62	390
10/28-30/79	8.6	.9	2.31	210
12/18-19/79[8]	8.9	2.7	.67	180
1/29-30/80	10.9	(2.5)	.16	40
3/10-11/80	10.0	2.3	.36	82
3/27-28/80	5.2	2.4	.29	69
Totals	**64.8**	**18.2**	**.68**	**1241**
Field 5, 1979-80 — sugarbeets, 60 ha				
9/22-24/79	11.7	3.3	.94	310
10/12-14/79	8.4	1.6	.69	110
11/7-9/79	13.3	2.4	.79	190
12/18-21/79	11.6	1.0	1.80	180
Totals	**45**	**8.3**	**.95**	**790**

[1]Mean concentration equals amount of sediment in runoff divided by volume of runoff water.
[2]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.
[3]First furrow irrigation of melon crop following cotton. Melons were planted in January 1981 and sprinkler irrigated in February.
[4]Only east ½ of field irrigated lightly.
[5]Estimated runoff based on a very low rate of < 0.1 ft^3/sec for approximately 24 hr.
[6]Flood irrigation after lettuce prior to planting cotton.
[7]First furrow irrigation to cotton after planting.
[8]Also irrigated 11/23/79, but no runoff samples were obtained.

Table 8. — *Sediment in irrigation runoff water from border irrigated fields in Imperial Valley, Calif.*

Runoff dates	Irrigation runoff: Water applied	Irrigation runoff: Runoff volume	Sediment in runoff: Mean concentration[1]	Sediment in runoff: Amount lost
	L/ha × 10^5 (cm)	*L/ha × 10^5 (cm)*	*G/L*	*Kg/ha*
Field 7, 1980-81 — alfalfa, 58 ha				
3/25-27/80	13.8	2.7	0.23	63
4/11-13/80	10.4	2.4	.46	110
5/7-8/80	17.2	1.4	.07	10
5/21-22/80	12.7	2.3	.29	66
8/4-6/80[2]	11.9	1.6	.48	77
8/13-14/80	9.4	2.4	.67	160
8/20-22/80	9.7	2.7	.63	170
9/5-7/80	12.5	2.2	.43	93
9/14-15/80	9.4	[3](2.0)	.45	90
9/26-28/80	10.0	1.9	.68	130
10/15-18/80	10.1	(1.1)	.81	89
11/3-5/80	9.9	2.6	.46	120
3/10-12/81	10.6	1.4	.14	20
3/27-28/81	5.9	(1.5)	.05	22
5/24-25/81	12.0	(2.0)	.25	50
6/18-20/81	13.4	(2.0)	.33	67
6/26-28/81	11.4	(1.8)	.42	75
7/5-7/81	10.0	(2.0)	.16	32
10/7-10/81	20.4	2.0	.70	140
Totals	**208.7**	**38.0**	**.40**	**1525**

[1]Mean concentration equals amount of sediment in runoff divided by volume of runoff water.
[2]Irrigated 5 times between 5/22/80 and 8/4/80 with no runoff samples taken.
[3]Runoff values in parentheses were estimated from partial hydrographs and/or other irrigations because of malfunction of water-stage recorder.

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